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(6)

PNEUMATIC CONTROL DEVICE

for the

PERSHING II ADAPTION KIT

(7) FINAL TECHNICAL REPORT

Contract DAAK10-77-C-0007

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Middletown, Connecticut

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1.0 SUMMARY

A preliminary operating model (POM) for the Pneumatic Control Device (PCD) has been developed and is in line with the referenced contractual requirements. The PCD preliminary design was formulated and documented in the 31 August, 1977 Interim Technical Report. Development effort for the pneumatic control POM includes the completion of all detail drawings and their revisions, breadboard tests of the reentry sensor and gas generator, fabrication of POM parts, assembly and evaluation of the first POM, gas generator tests with POM parts for the generator and valve, interface and demonstration of PCD with SACA POM units, preparation for and completion of the twelve (12) contractually required gas generator tests, support of the five (5) gas generator/turboalternator compatibility tests at Garrett, analysis and verification testing of cold gas generator anomally observed during compatibility tests, completion of the preliminary safety and reliability analysis, and preparation of associated software.

2.0 TECHNICAL REPORT

2.1 Requirements

Phase I requirements are to conceive, design, develop and test a preliminary operating model of the PCD, meeting the contractual statement of work. This final report documents the program effort throughout the contract covering the POM development and test.

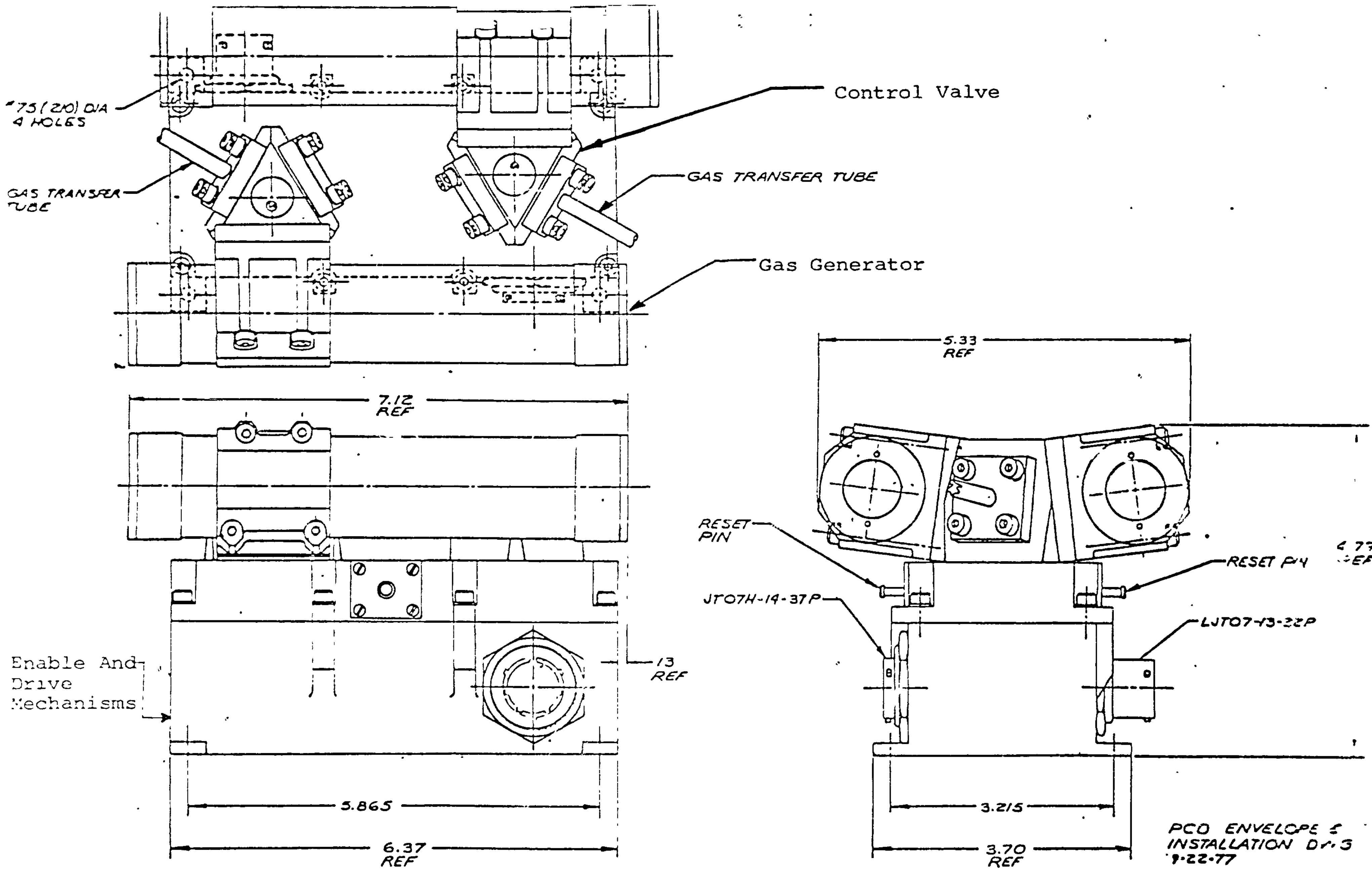
2.2 PCD Description

A brief description of the PCD preliminary design will be presented in the following paragraphs. For a more detailed description refer to the 31 August, 1977 Interim Technical Report.

The PCD, shown in Figures 1 and 2, and 3 is a dual channel, failsafe, electromechanical device consisting of two motor driven control valves, two code operated enable mechanisms and two hot gas generators. The function of the PCD is to produce hot gas for the Warhead Power Converter Assembly (WPCA) turboalternator upon receipt of the correct type and sequence of electrical signals from the Safing/Arming Control Assembly (SACA). The WPCA, PCD and SACA are components of the Pershing II Missile Adaption Kit.

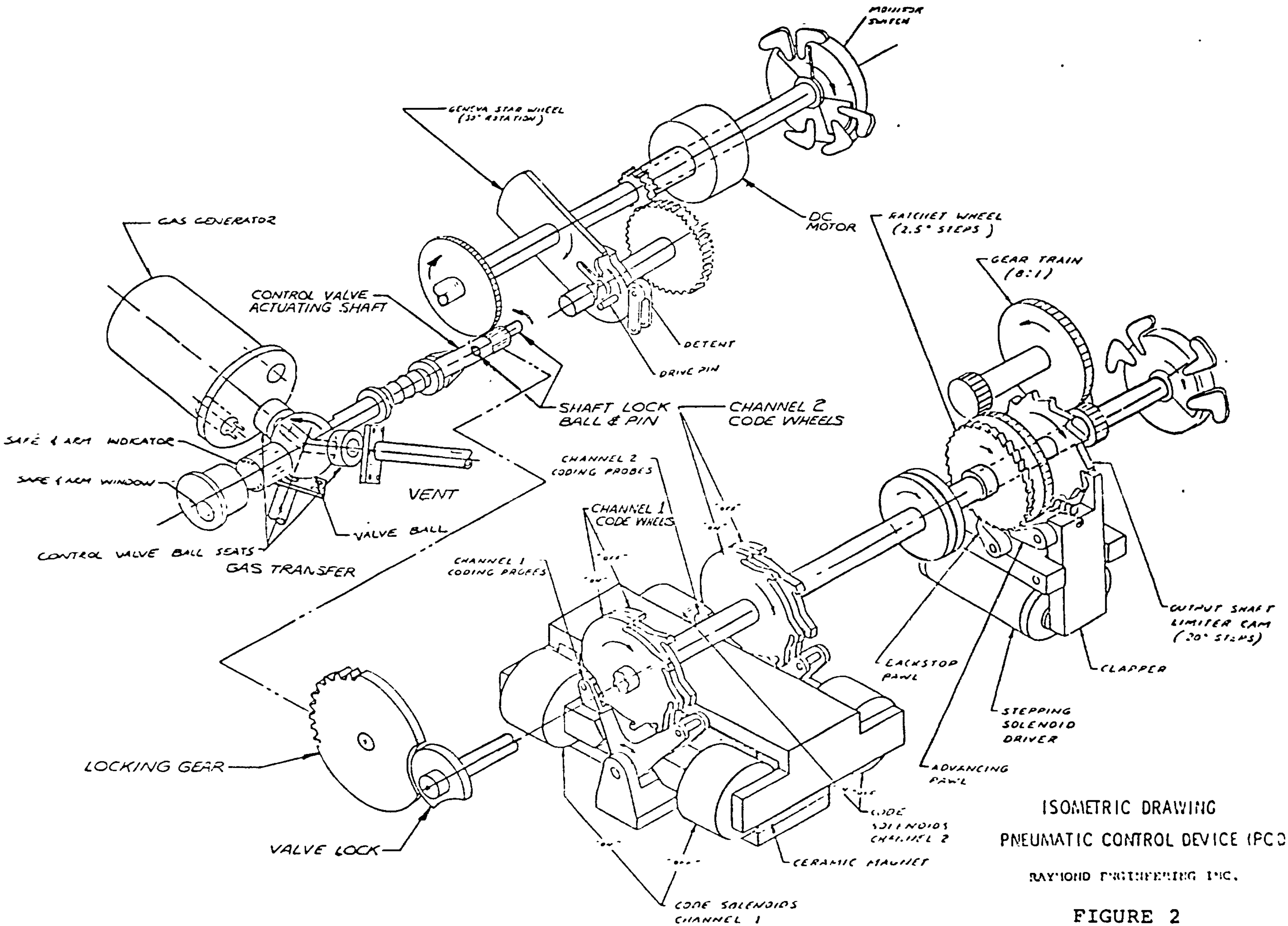
A reentry sensor initially intended to be an integral part of the PCD was developed as a separate unit. The function of this device is to respond to missile deceleration and close a normally open switch external to the PCD valve driver power circuit. This POM, as shown in Figures 4 and 5, is a dual channel unit consisting of two rotary switches, two 5g deceleration sensors, two rotary solenoid detents and a monitor switch.

In order for the PCD to operate, i.e. supply hot gas to the WPCA, the control valve must be driven from the safety vent to the armed position with a SACA good separation signal. Then the gas generator must be initiated by a SACA firing signal. Two valve shaft locks and one switch have to be activated by the PCD's enable mechanism prior



Control Valve
GAS TRANSFER TUBE
Gas Generator
.73 (2.10) DIA
4 HOLES
GAS TRANSFER TUBE
7.12 REF
Enable And Drive Mechanisms
.13 REF
5.865
6.37 REF
5.33 REF
RESET PIN
JT07H-14-37P
RESET PIN
LJT07-13-22P
4.77 REF
3.215
3.70 REF
PCO ENVELOPE & INSTALLATION Dwg
9-22-77

FIGURE 1



ISOMETRIC DRAWING

PNEUMATIC CONTROL DEVICE (PCD)

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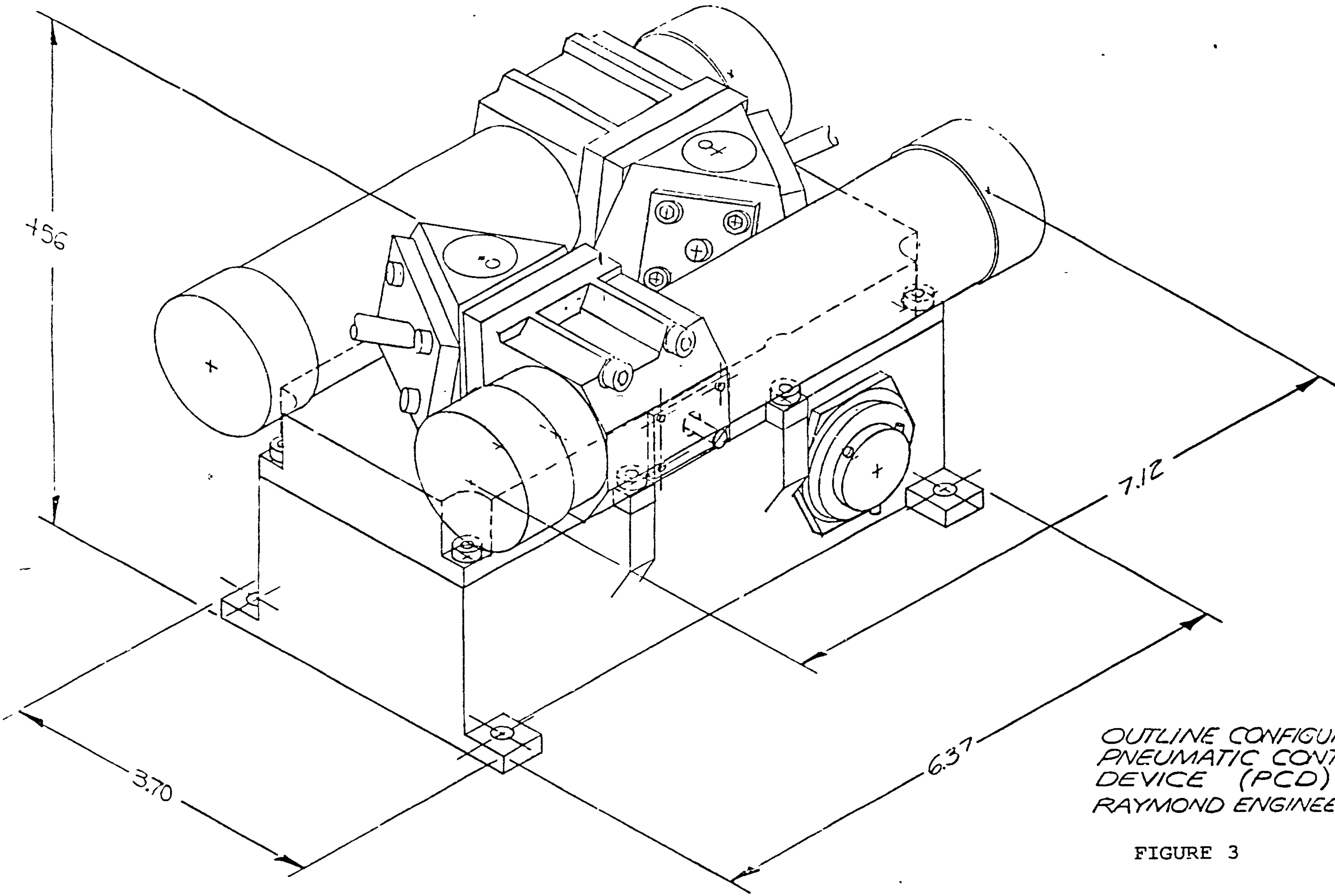
FIGURE 2



OUTLINE CONFIGURATIO
PNEUMATIC CONTROL
DEVICE (PCD)
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FIGURE 3

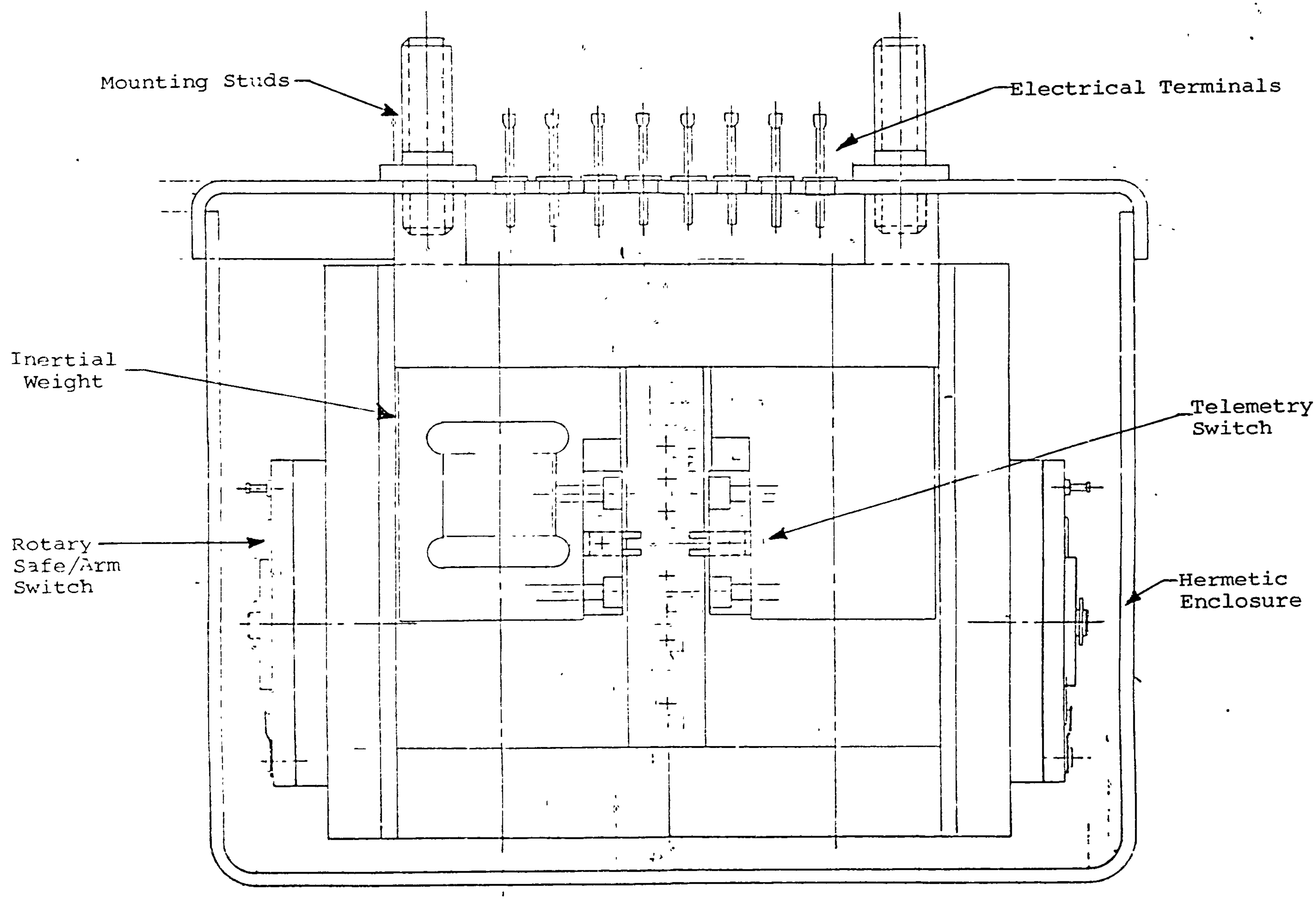
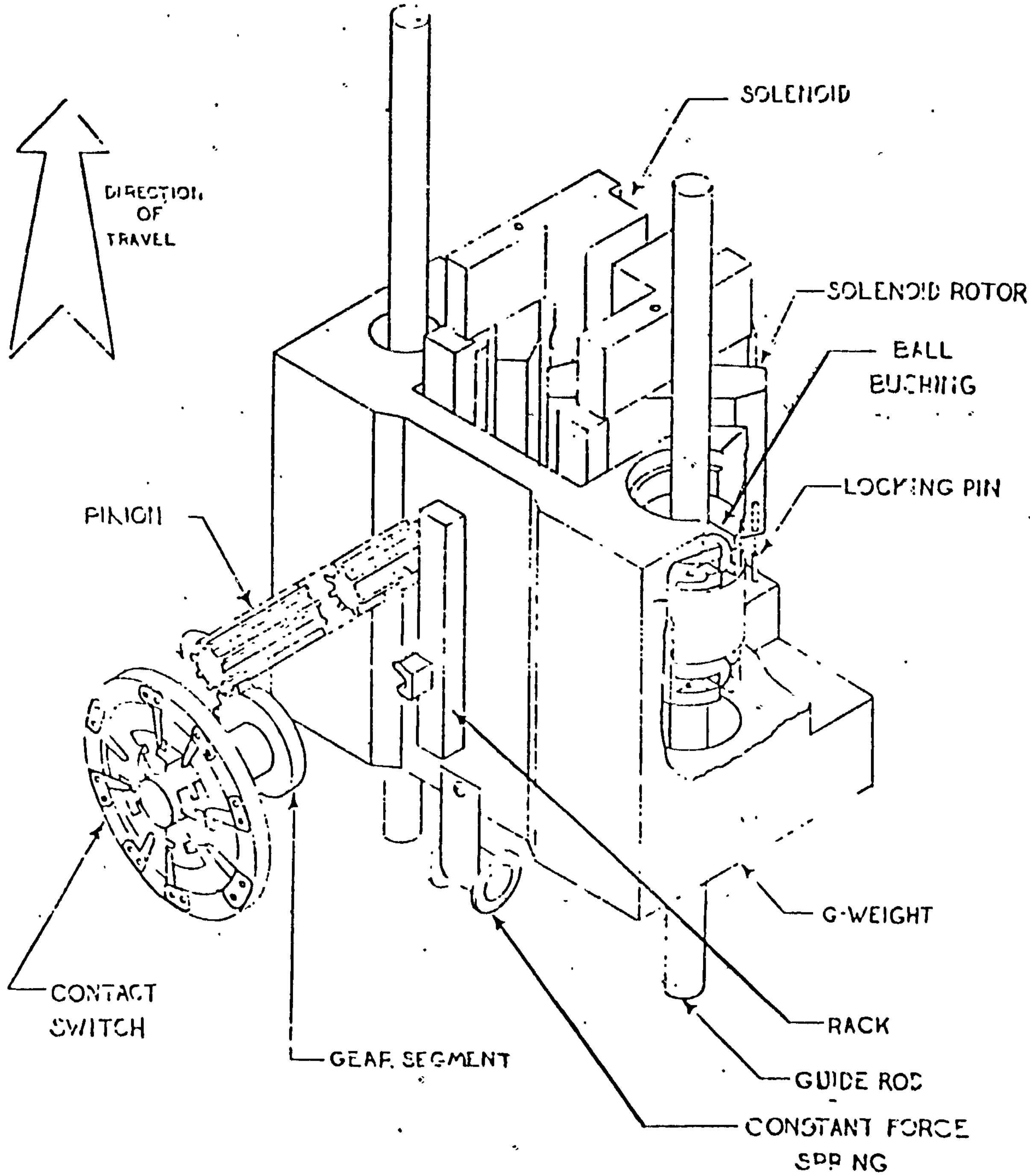


FIGURE 4 REENTRY SENSOR PACKAGING DESIGN



REENTRY SENSOR

PNEUMATIC CONTROL DEVICE

FIGURE 5

to the SACA drive signal or the gas generator will dud. Also a switch has to be closed by the valve drive mechanism prior to the firing signal or the generator will dud.

The valve enable mechanism rotates its output shaft 240 degrees for unlock, in a series of twelve (12) coded steps at a rate of 32 milliseconds per step. The SACA provides each channel of the enabler with a coded signal consisting of a 4-line-12-bit code with a synchronized clock pulse to drive the enable mechanism through each step checking the electrical code against the mechanical code wheels. If the proper code is received, the enabler will complete its rotation which mechanically unlocks the control valve's internal ball detent and the cam lock in the valve driver's gear train. Also at the end of this rotation the enable mechanism electrically connects the valve driver to the good separation circuit.

The valve drive mechanism requires a signal from the SACA to power the drive motor rotating the control valve 120 degrees to the arm position after the normally open enable mechanism switch has been activated. The rotation of the valve drive shaft provides for the alignment of the valve through a geneva mechanism and the removal of a shunt on the gas generator initiators by closing the switch from the initiators to the firing circuit.

When the gas generator is initiated by the SACA firing signal a hot gas is produced for a minimum of 55 seconds with a boost for a maximum of the first 5 seconds operating the WPCA turboalternator.

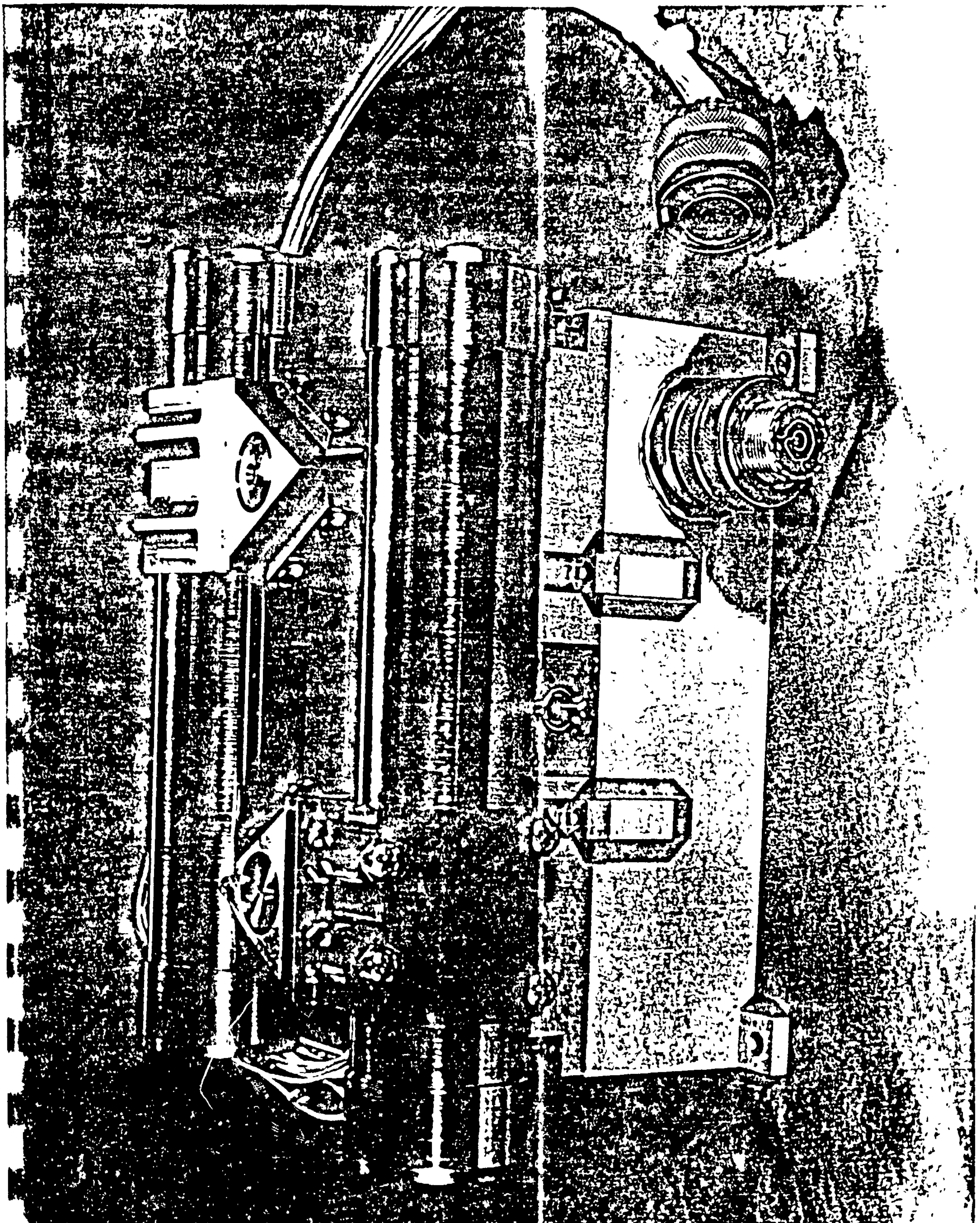
The gas generator is attached to the control valve with four (4) bolts and four (4) connectors such that it can be removed for system testing. The initiator leads protrude from the generator housing as male pins to mate with female connectors in the control valve. An adapter can be attached to the valve allowing for a cold gas test of the system.

The entire PCD mechanism can be actuated through complete duty cycles, including the flow of cold gas through the valve and transfer tubing. The actuated PCD can be reset, first electrically, then mechanically and then pulsed with a clock signal to position the code wheels at zero. If an error is introduced into the coded input, the enable mechanism will dud prior to unlock and can be reset by mechanical means only.

2.3 POM Demonstrations

A preliminary operating model (POM) for the Phase I PCD design was fabricated and assembled during the fifth through ninth months of this program. Also during this time a complete set of POM detail drawings were prepared and revised during the assembly effort. Subassemblies were put together and evaluated as the POM parts became available. Bench tests for fit and function were performed for the appropriate mechanical and electrical subassemblies.

The POM, as shown in Figures 6 through 11, consists of dual valve enable and drive mechanisms packaged inside an aluminum housing. The SACA electrical inputs are hard wired through a connector to the PCD components. Monitoring circuits were available but not connected



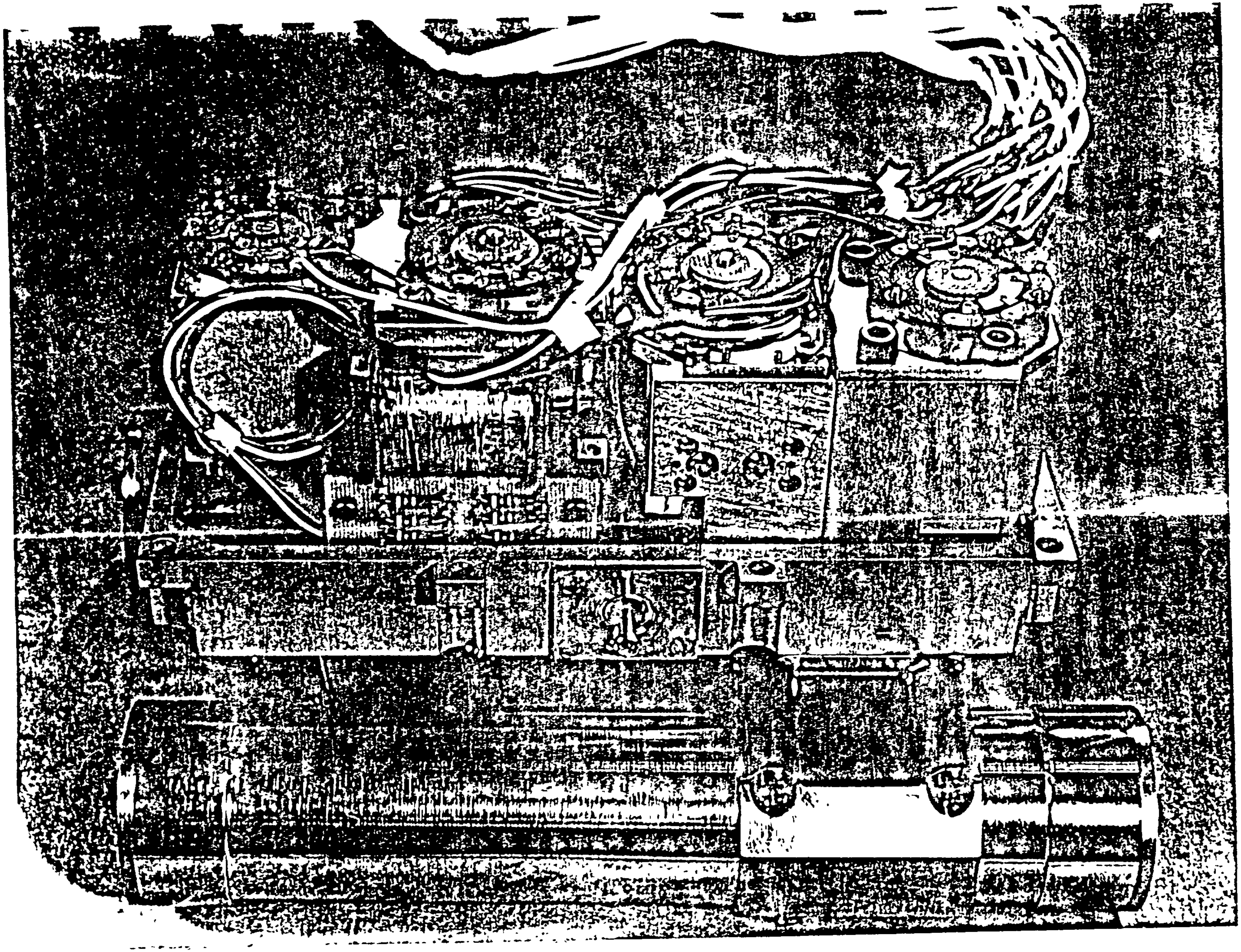


FIGURE 7 PCD MODEL

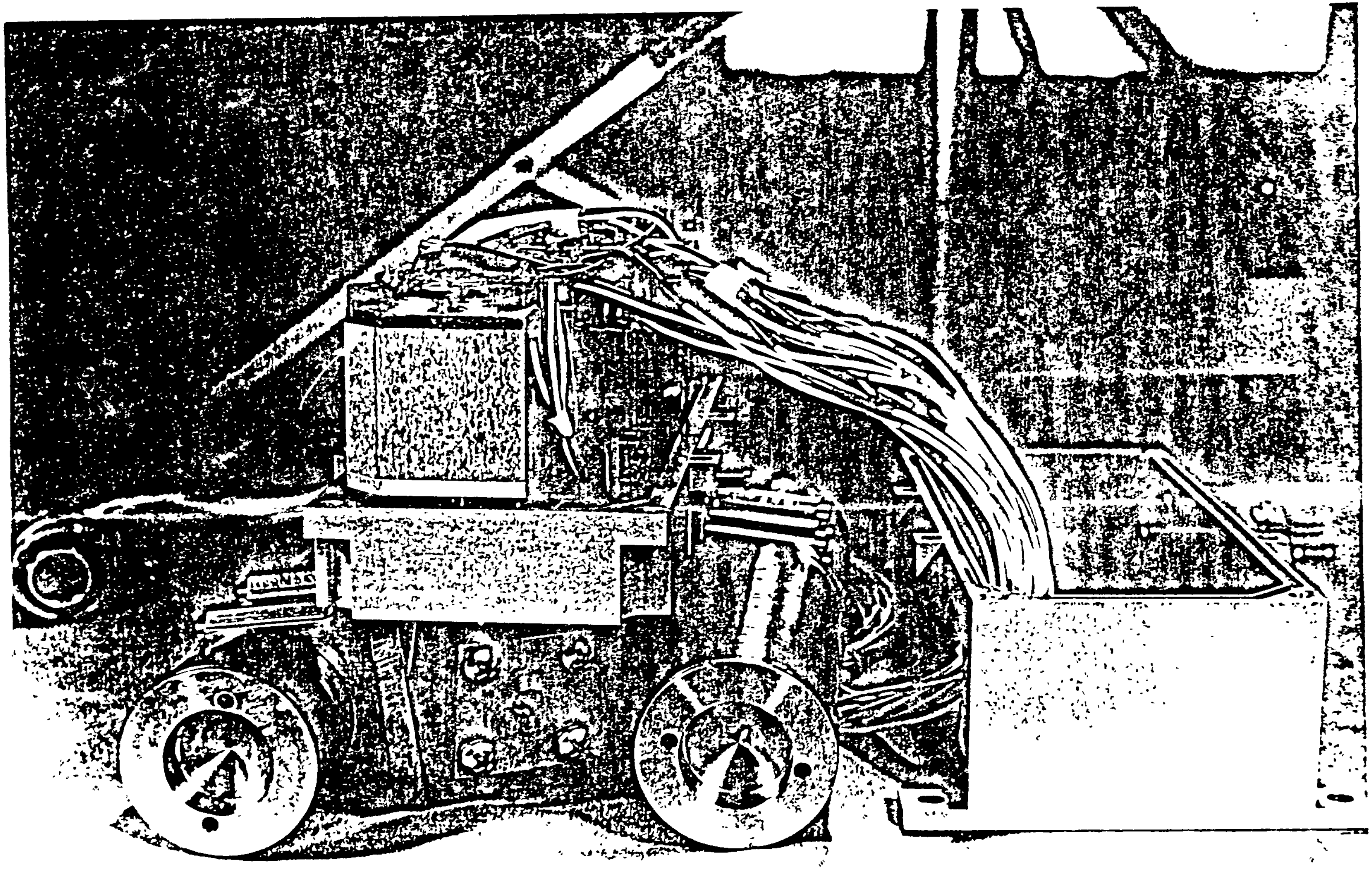


FIGURE 8 PCD MODEL

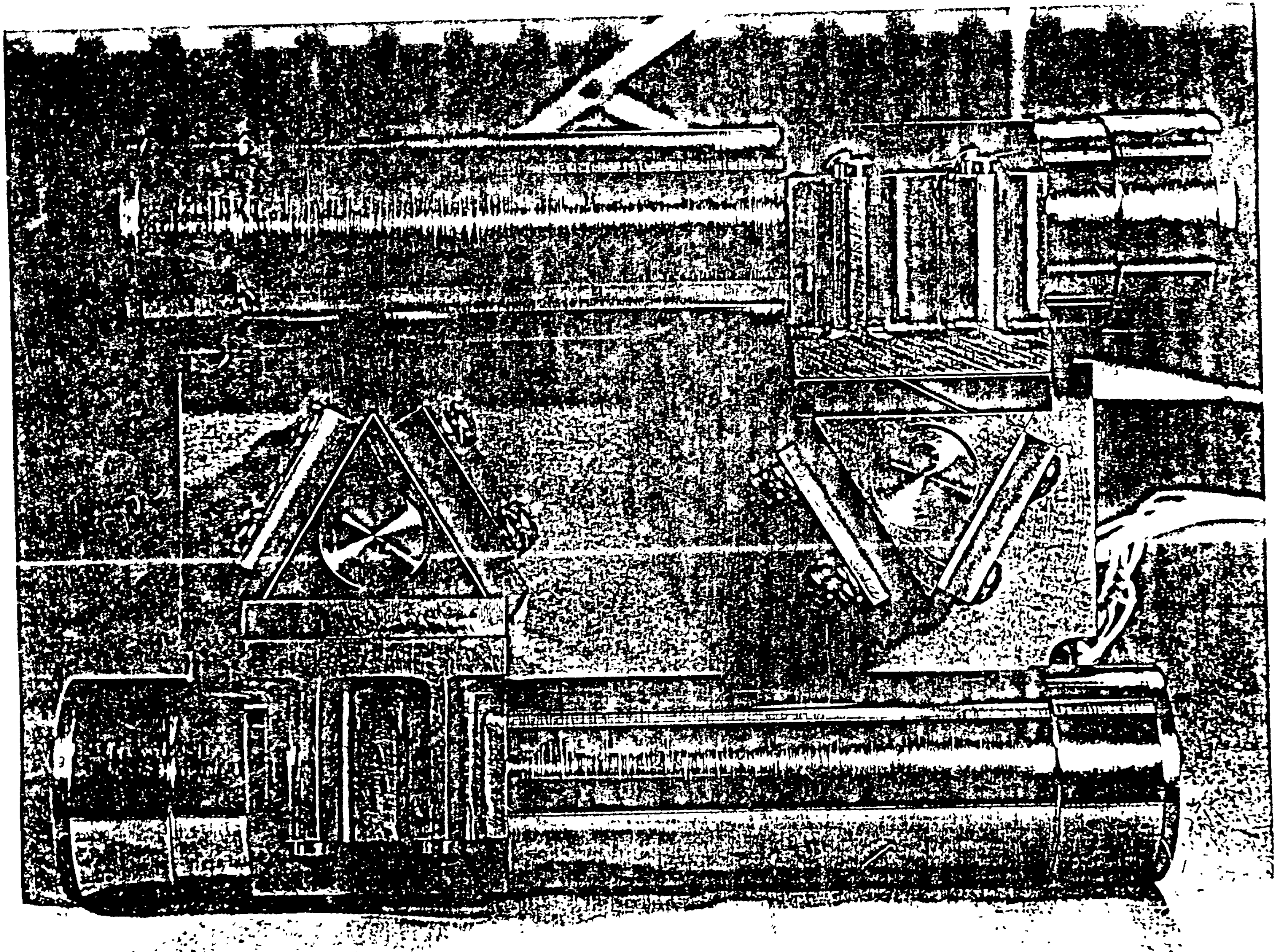


FIGURE 9 PCD MODEL

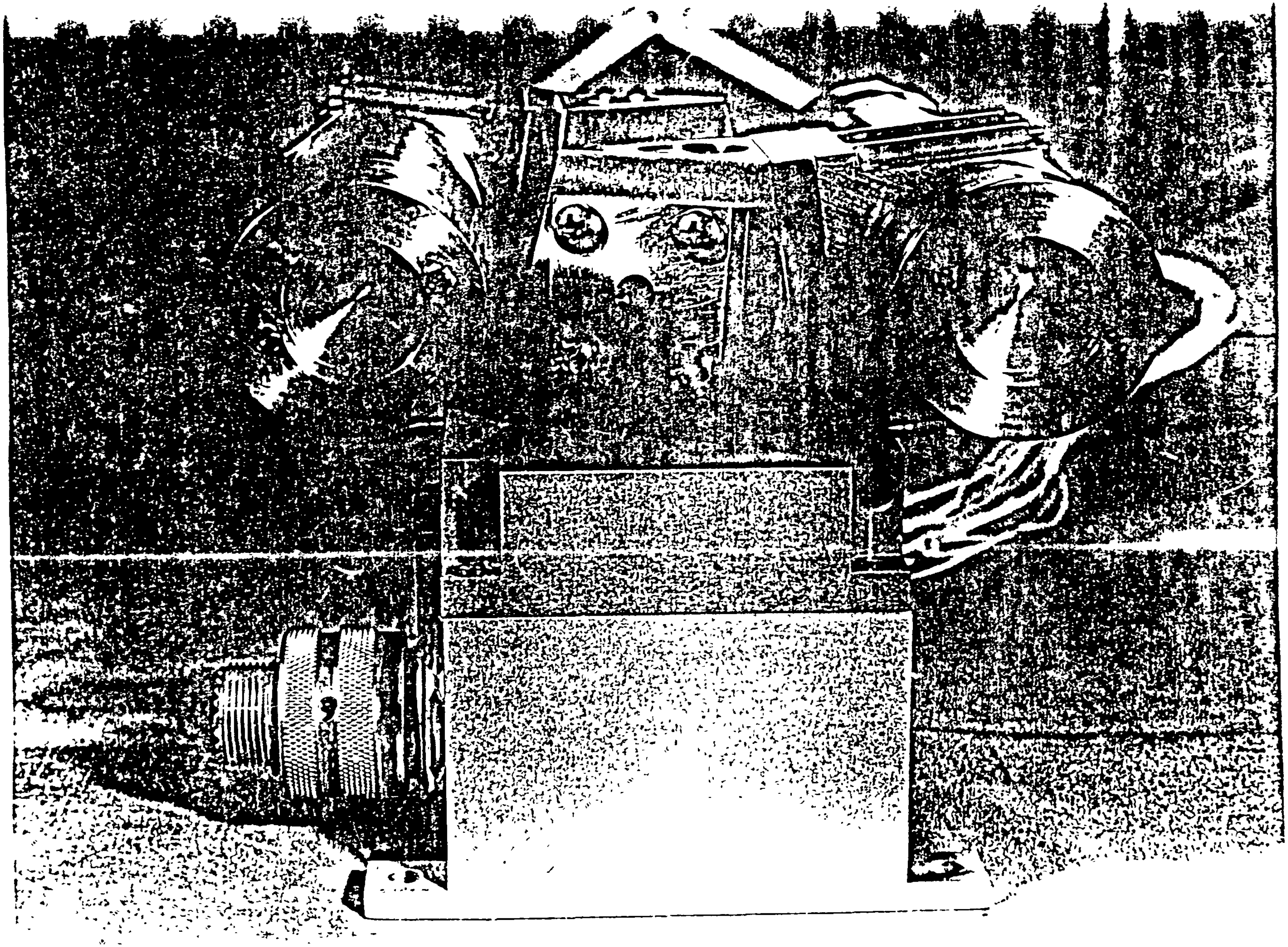


FIGURE 10 PCD MODEL

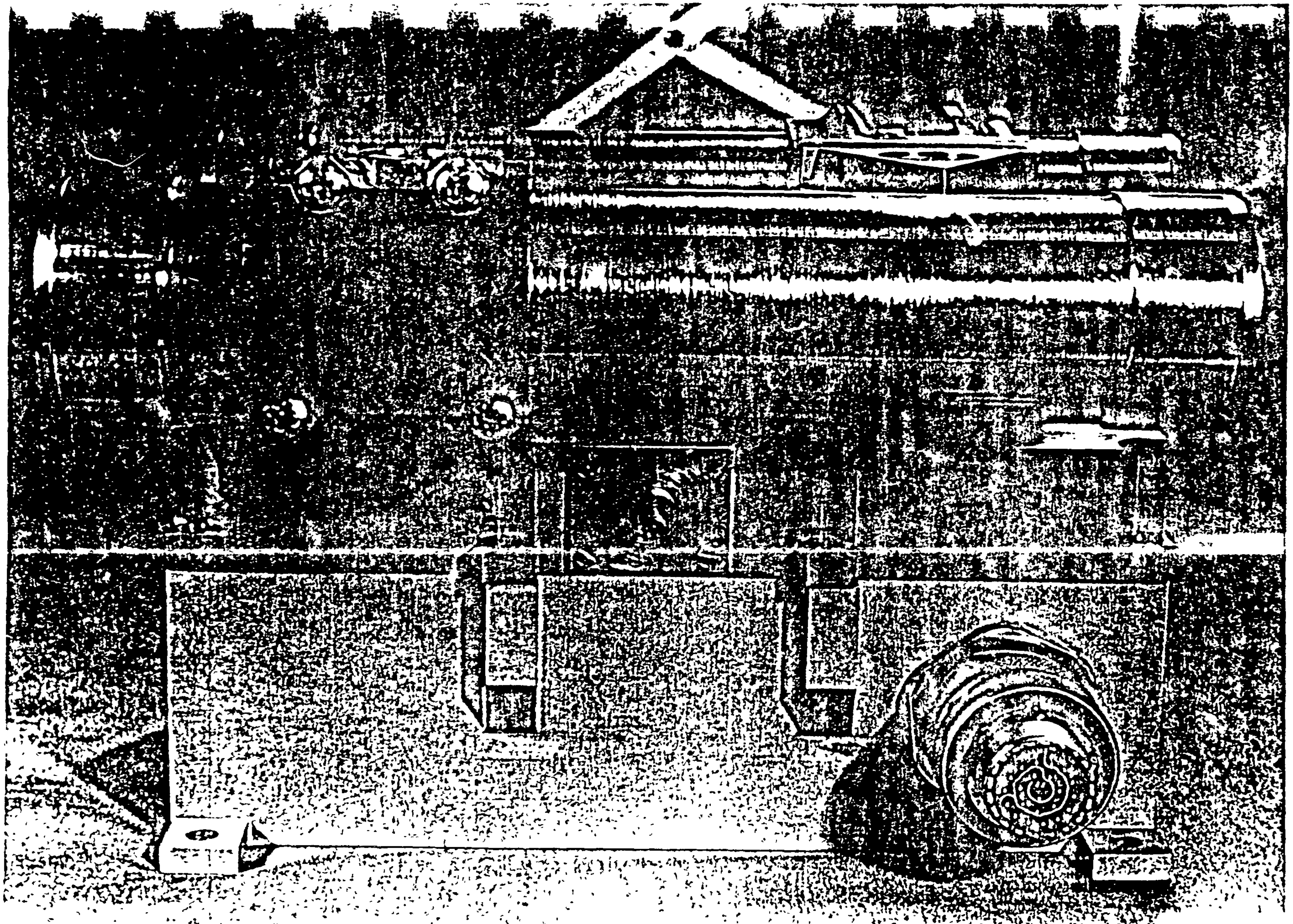


FIGURE 11 PCD MODEL

for the POM demonstration. Integral with the top housing are two control valves and their mating gas generators. The wires from the male/female pin type connectors for the gas generator run inside the sealed control valve to the enable and drive housing. Both gas generators for the POM are inert assemblies of metal parts only. The POM control valves are assembled to operate with the drive mechanism and not during a hot gas firing as discussed in the valve development section.

An early POM was assembled for display during the PII Safety Review Meeting at ARRADCOM the week of 14 November 1977. One channel of the enable and drive mechanism was functional at this time. This component was assembled into the PCD housing with both control valves and inert gas generators. Electrical connectors used to provide a disconnect capability for the generator and valve were included in the POM. The enable and drive mechanism was not demonstrated. This early POM was strictly a display unit.

Several modifications to the POM enable and drive mechanism were required before the first demonstration. No modifications were required to the POM control valves or inert gas generators.

The first channel of the coded enabler was adjusted during November to accept the required code and lock up for an incorrect code in any of the twelve code bits. The enable device locking mechanisms for the control valve required adjustments to operate the valve properly. When the cam surfaces were modified, they would lock and unlock the

control valve as required during drive and reset. The valve drive subassembly was operational and did not require modification during assembly.

A second channel of the enable and drive mechanism was assembled for a POM demonstration at Avco the 19th and 20th of December, 1977. At this time the enable units functioned through twelve (12) code positions and were pulsed to the eighteenth position by the SACA electronic simulator. This opened the valve driver switch during the good separation signal preventing the operation of the motorized control valve.

The first POM demonstration met with limited success due to the extra code pulses but proved the SACA 12-bit code signal would function the PCD enabler. Avco determined the SACA could readily be changed to issue only twelve (12) code bits.

Before the next demonstration both the SACA and PCD units required changes stemming from the first POM interface. The PCD reset mechanism for the coded enabler required modification to assure the zero-code position after reset. When reset, the POM would intermittently stop at the first code position and be out of sequence to receive the code. As such the coder would lock up between the off-code stop and the reset stop. To correct this problem, the reset mechanism was changed to drive the coder one position beyond the zero start and required a clock pulse to step the coder into the zero position. This position can be monitored by the closing of the enable mechanism telemetry switch. Also the POM was evaluated for

possible design weaknesses by bench tests prior to the second demonstration. Areas of the POM that were up graded after this evaluation included the code limit cam's back stop pawl, the friction clutch in the valve driver, the geneva output wheel attachment to the drive shaft, the code probe positioning through the permanent magnet assembly, the routing and fastening of the code solenoid wires.

A demonstration of the POM units was performed during the SACA/PCD/WPCA Technical Review Meeting at Avco on the 5th of January. When the PCD model was assembled for this meeting a code solenoid in channel one was found to be inoperative. The solenoid was in and out of the assembly so many times during evaluation that the lead wires became disconnected from the solenoid windings. There was not enough time to correct this problem prior to the second POM demonstration. Channel two functioned completely accepting the coded signal from the SACA simulator which unlocked the control valve and drove the valve to the armed position. The single channel POM was electrically and mechanically reset and successfully rerun three times. After this demonstration the damaged code solenoid in channel one was replaced and the POM was fully operational.

For the next three POM demonstrations at Avco, both channels of the PCD functioned completely and repeatedly. The SACA electronics and S&A's went through several revisions between these tests to improve the PASD and ESAD codes sent to the SACA microprocessor and to correct the SACA code sent to the PCD. Until the last demonstration

the PCD was operated by a SACA electronic flight simulator and not the actual SACA POM devices. For the last test the SACA microprocessor was reprogrammed to send the correct code to the PCD when the S&A codes were stored in its memory. The PCD was connected to the SACA units and all the PII POM's were sequenced to simulate missile trajectory. Both channels of the POM enable and drive mechanisms unlocked the control valve and drove the valve to the armed position. The PCD model was electrically and mechanically reset and rerun three (3) times with the SACA signals.

The last POM demonstration concluded the PCD program for Phase I design, development and evaluation of a preliminary operating model. At this time, it is felt the coded enable mechanism will not require redesign for the next phase except for minor changes to improve the necessary adjustments at assembly. The valve drive mechanism will require redesign during Phase II to deliver additional torque needed for the hot gas control valve as explained in the next section. Gas generator development has been separated from the POM demonstrations during this program and has evolved to a design that meets the Phase I specification.

2.4 Control Valve Development

The first POM of the control valve was assembled and evaluated through testing in the eighth month of the PCD progr ~. A sealing problem was discovered at this time. Using the parts as manufactured for this model, the valve would not seal for cold gas pressures over 150 psi. The problem was determined to be the surface finish of the

titanium ball and the type of carbon graphite material used for the wedge seats. The surface roughness height specified for the valve ball was 13 microinches and flaws in the surfaces were approximately 32 microinches. This made it difficult to lap he wedge seats in the valve assembly without damaging the carbon graphite seal. To test this theory, the carbon graphite seats were resin impregnated improving the materials density and scleroscope hardness. Also a K-monel ball bearing with a mirror finish was machined to provide the valve ports and shaft attachment. These parts were evaluated with the POM control valve towards the end of December. Valve shaft springs from five to ten pounds were fabricated to load the wedge seats during these evaluation tests. The control valve would seal up to 350 psi with the impregnated wedge seats, the K-monel ball and a ten pound shaft spring. Test data for this evaluation is as follows:

Shaft Spring (lbs.)	Torque (in-oz)	Seal Pressure (psig)
2[(1)]	6 - 12	150
5	18 - 24	250
6	24 - 30	275
7	28 - 34	300
10	40 - 48	350

Note: [(1)] Preliminary design spring for the POM valve.

The test setup consisted of a cold gas source with a regulator and pressure gage connected to the control valve generator port. The output port was blocked and the valve ball was in the armed condition

which connects the input and output ports. Torque to rotate the ball valve in its wedge seats increased with the spring bias as expected. The valve would seal tightly until the cold gas pressure increased to a level beyond the wedge seat bias and caused the sealing surfaces to be forced apart. A loud popping sound was heard when the wedge seals lost contact. Force analysis performed for the preliminary design control valve showed the friction force of the wedge seats to be greater than the unseating force on the ball during gas operation. From this analysis a two (2) pound shaft spring was designed to preset the wedge seats while limiting the torque required to rotate the ball. The POM valve tests indicate the coefficient of friction chosen for this force analysis was in error. At this point REI decided to redesign the control valve to prevent unseating of the wedge seal ball valve.

The control valves used for the PCD model, shown in Figure 12, remained in the preliminary design configuration with a two (2) pound bias spring. These valves functioned successfully with the drive mechanism and were not required to operate with hot gas because the POM generators were inert assemblies. The technical impact of this sealing problem indicates the axial load on the wedge seats must be increased which in turn will increase torque required to rotate the ball valve. The POM valve driver will presently delivery 36 in-oz of torque to the control valve shaft. Increasing the driver output is not considered to be a problem and can readily be redesigned during the second phase of the PCD development program. Three options are available for this change, namely, increasing the output of the drive

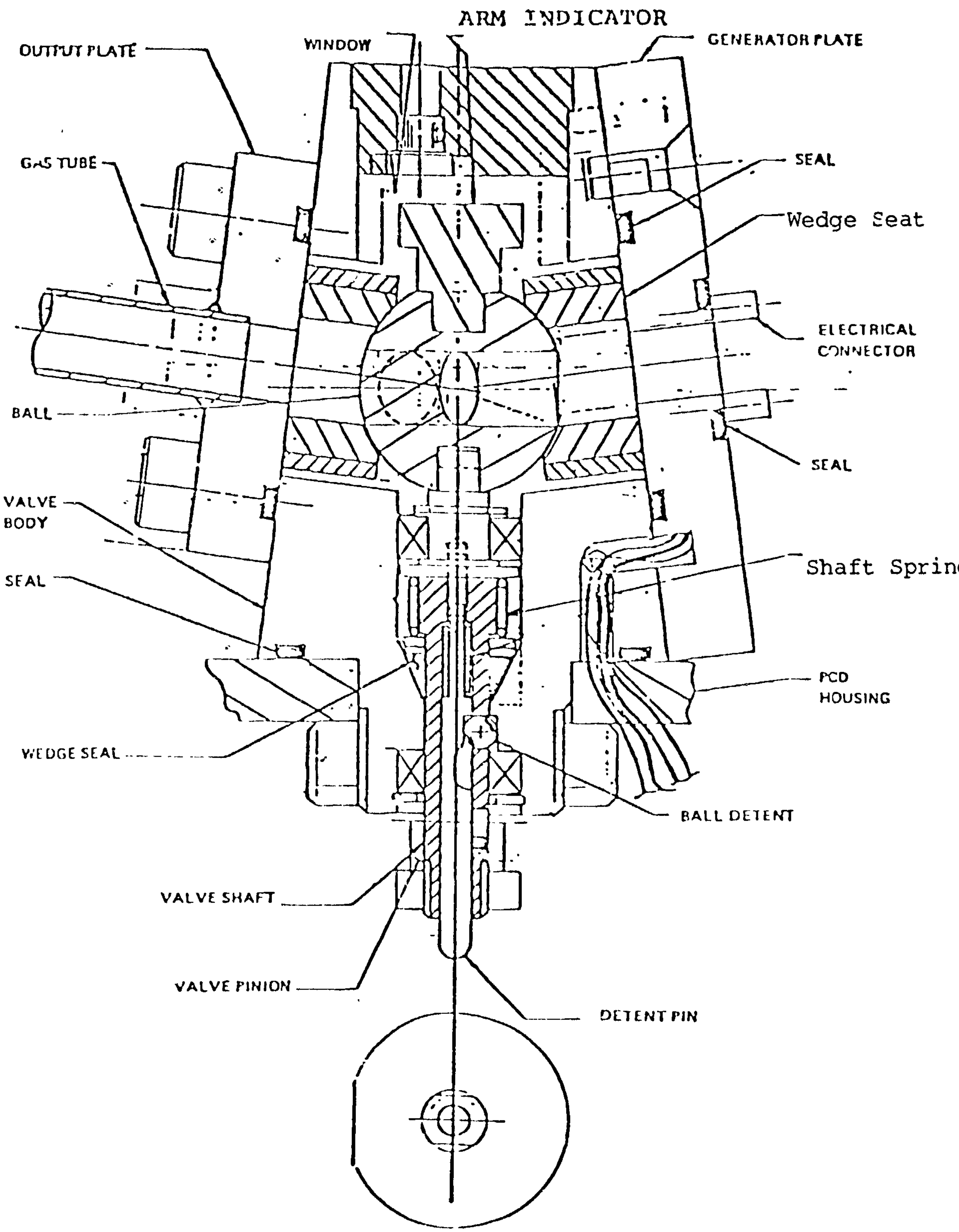


FIGURE 12 CONTROL VALVE
(BEFORE REDESIGN)

motor, increasing the drive gear train and a combination of the preceding alternatives.

Redesign of the control valve was completed in tenth month providing a one way ball lock for the wedge seats. This modification was intended to prevent the ball from being forced out of its wedge seats during gas operation and maintain the required seal under environmental tests. Figure 13 shows a pressure bushing and one of three spring biased keeper balls which allow the valve shaft to move only in the direction that would wedge the valve ball in its seats. Movement of the ball to unseat the sealing surfaces would be prevented by three keeper balls integral to the valve body and in contact with the control ball shaft assembly. Other changes to the control valve made during the redesign increased the density and hardness of the wedge seat material and improved the surface hardness and finish of the valve ball. The valve ball was plated with an extremely hard electrodeposited chromium to increase the surface hardness and lower the coefficient of friction during rotation of the seated ball. The carbon graphite seats were changed from grade 80 to 110 which increased the scleroscope hardness by fifteen (15) percent and the density by six (6) percent.

Fabrication of parts for the redesigned control valve occurred during February and the valve was assembled in early March 1978 for evaluation tests. During assembly a matched set of wedge seats are lapped inside the valve by rotating the ball. This process was enhanced by the one way ball lock design for the wedge seats. A constant

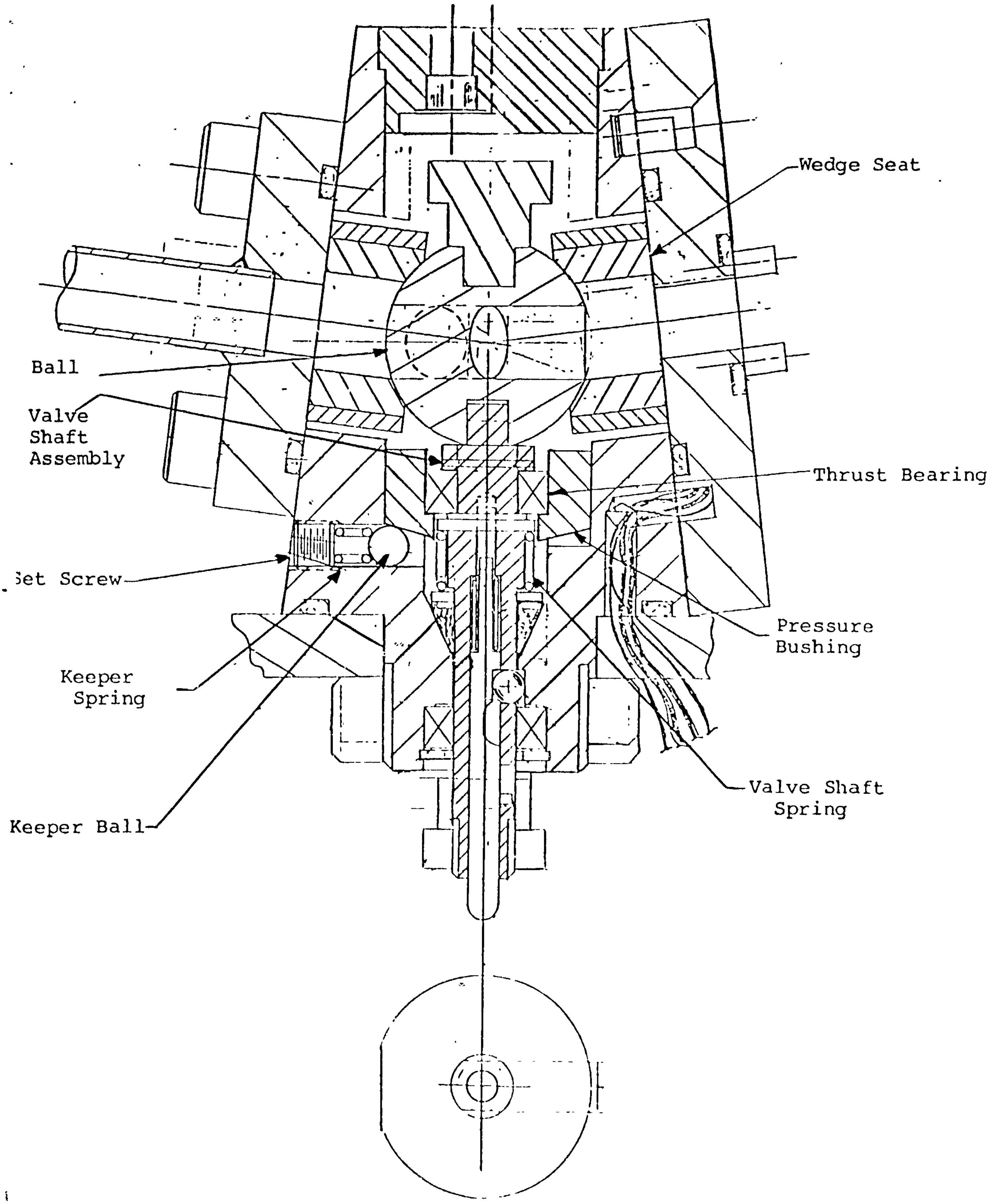
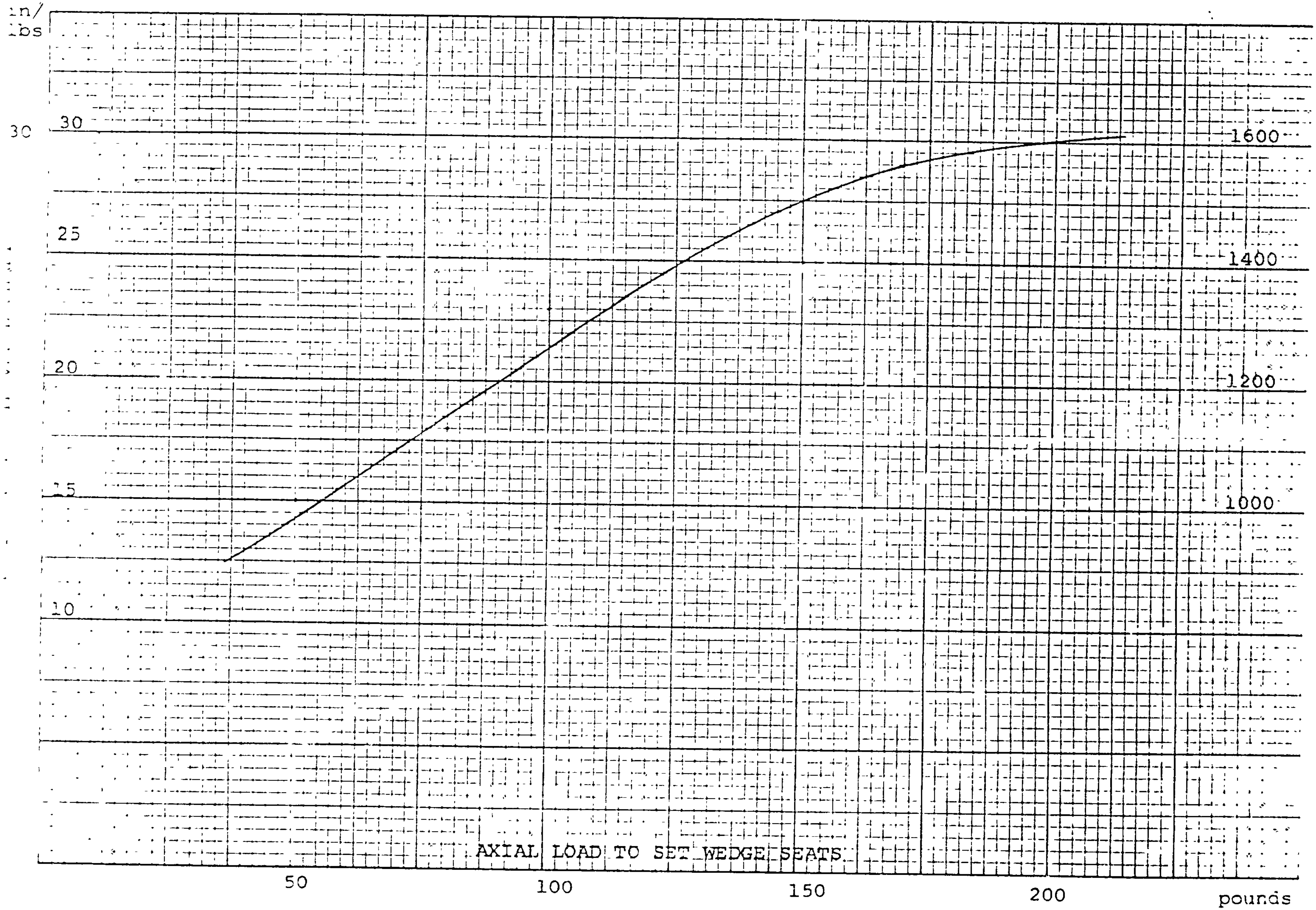


FIGURE 13
REDESIGNED CONTROL VALVE

force maintained on the seats while the sealing surfaces are lapped greatly improved the surface smoothness of the carbon graphite material. Prior to the one way ball lock design the carbon graphite lapping operation did not produce a smooth, scratch free,sealing surface.

A number of tests were performed to evaluate the redesigned control valve. The gas seal was drastically advanced by the one way lock for the wedge seats. Valve tests with cold gas demonstrated tight seals for pressures over 1500 psig. The test set up included a flow nozzle connected to the valve output port and pressure monitoring equipment attached to both input and output ports. The valve was set in the armed position and the flow from a cold gas source through the valve was controlled by the same .023 inch nozzle used for the gas generator tests. Pressure drop through the valve was negligible during these tests. Springs chosen for the valve shaft and the keeper ball locks represented an equivalent axial load of 21.8 pounds and were insufficient to seat the wedge seals for high pressure. To attain higher seal pressures with the existing hardware axial loads were applied to the wedge seats through the valve shaft presetting the one way ball lock design. This allowed the keeper balls and the pressure bushing to lock the wedge seats at a compression level relative to the applied loads. During the tests, gas pressures were recorded at the first sign of wedge seat leakage. When the seats began to leak, gas pressure could be raised one to two hundred psig without experiencing excessive pressure drop through the valve. Figure 14 shows the cold gas pressures at which

FIGURE 14 CONTROL VALVE TEST DATA



the primary valve seal (wedge seats) began to leak for different axial load levels. The torque required to rotate the ball valve was measured and is shown in Figure 14 as a function of the axial load set into the one way lock design.

Next the control valve design was analyzed to determine the necessary shaft and keeper springs for self sealing wedge seats under gas pressures of 2000 psi. The maximum shaft spring that could be designed into the limited space available was determined to have a twenty-six (26) pound working load. Keeper springs were adjustable through a set screw and were chosen to load the keeper balls from 1.5 to 5 pounds, which through the pressure bushing would equate to axial load from 16.8 to 56 pounds. New springs were fabricated for the valve redesign and tests were performed which showed, at an equivalent axial load of forty-eight (48) pounds, the valve would self seal for pressures up to 1550 psig.

Test data from this evaluation is as follows:

Spring Loads (lbs)		Equivalent	Valve Shaft	Seal(psig)
Keeper	Shaft	Axial Load (lbs)	Torque (in-lbs)	Pressure
1.5	26	43	28	1300
2	26	48	33	1550
2.5	26	54	38	1800
3	26	60	43	2050

The results of this test indicates the control valve is ready to be tested with the hot gas generator. As stated before the additional torque required to rotate the ball valve is not anticipated to be a problem for the valve drive mechanism. In designing to provide a one-way wedge seal and ball valve, which established a tight hot gas seal and prevented the seal from unseating during gas pressure, the valve was not sensitive to shock environments as before. Refer to Appendix E, Ball Valve Wedge Analysis.

2.5 Gas Generator Development

The POM gas generator consists of dual propellant gains and central ignition to provide a 2.5 to 1 initial boost for a duration of five (5) seconds maximum and a sustained output for a total of 55 seconds minimum. Other designs were considered for the required boost such as a single grain with two diameter, but were impractical from a packaging standpoint. The gas generator requirements that established the initial design are shown in Figure 15. The initial POM generator design, Figures 16 and 17, has electrical connectors that allow the generator to be detached from the PCD control valve. Two (2) electric squibs initiate the central igniter pallets which fire directly at both propellant grain surfaces. The central igniter initiates the dual propellent grains simultaneously to obtain the required boost and sustain phase. The gases generated are directed to the central valve port by an annular manifold around the igniter basket which provides a large surface for filtering as required.

The gas generator design for the PCD preliminary operating model has undergone a series of improvements in conjunction with development testing.

SOLID PROPELLANT CHARACTERISTICS
OF HOT GAS SUPPLY FOR PERSHING II TURBOALTERNATOR

SUSTAIN		BOOST	
P_{min}	= 420 psia	P_{min}	= 900 psia
P_{max}	= 634 psia	P_{max}	= 1396 psia
GHP_{min}	= 1.148	GHP_{min}	= 2.75
GHP_{max}	= 1.866	GHP_{max}	= 4.53
T_{max}	= 1800°F	T_{max}	= 1800°F
W_{min} (REF)	= .0015 lb/sec	W_{min} (REF)	= .0031 lb/sec
W_{max} (REF)	= .0022 lb/sec	W_{max} (REF)	= .0049 lb/sec

Generator gas should be filtered and the maximum permissible particle is .001 inch in diameter,

Ambient Temperature MAX = +125°F

MIN = -29°F

NOTES:

1) The total burn time shall be 55 seconds and the boost phase shall not exceed 5 seconds.

2) The transition from boost to sustain phase shall be smooth.

3) Final approval of propellant requires review for compatibility with the turboalternator and other components within the system.

4) Nozzle area (nom) = .000409 in^2

FIGURE 15

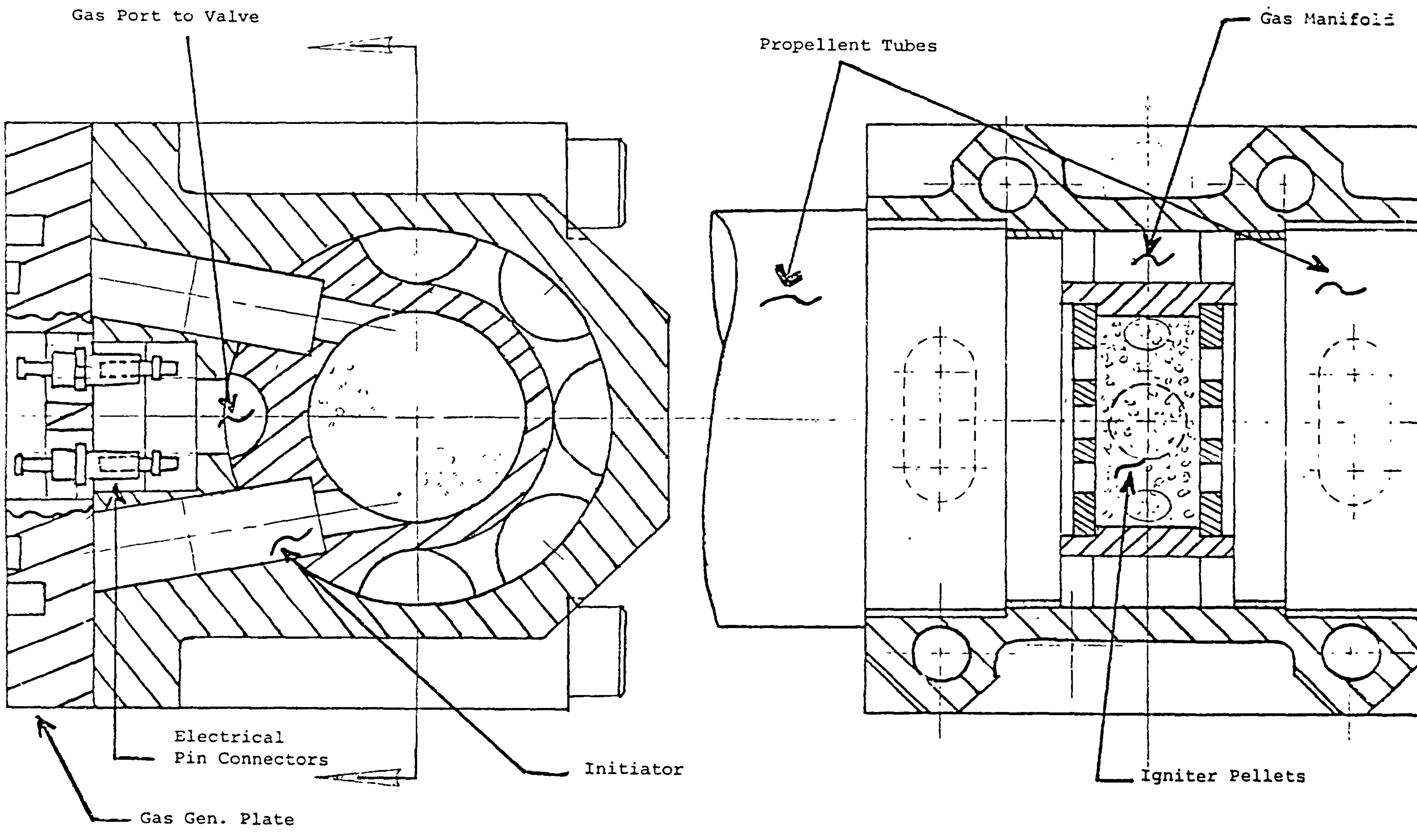


FIGURE 16 GAS GENERATOR

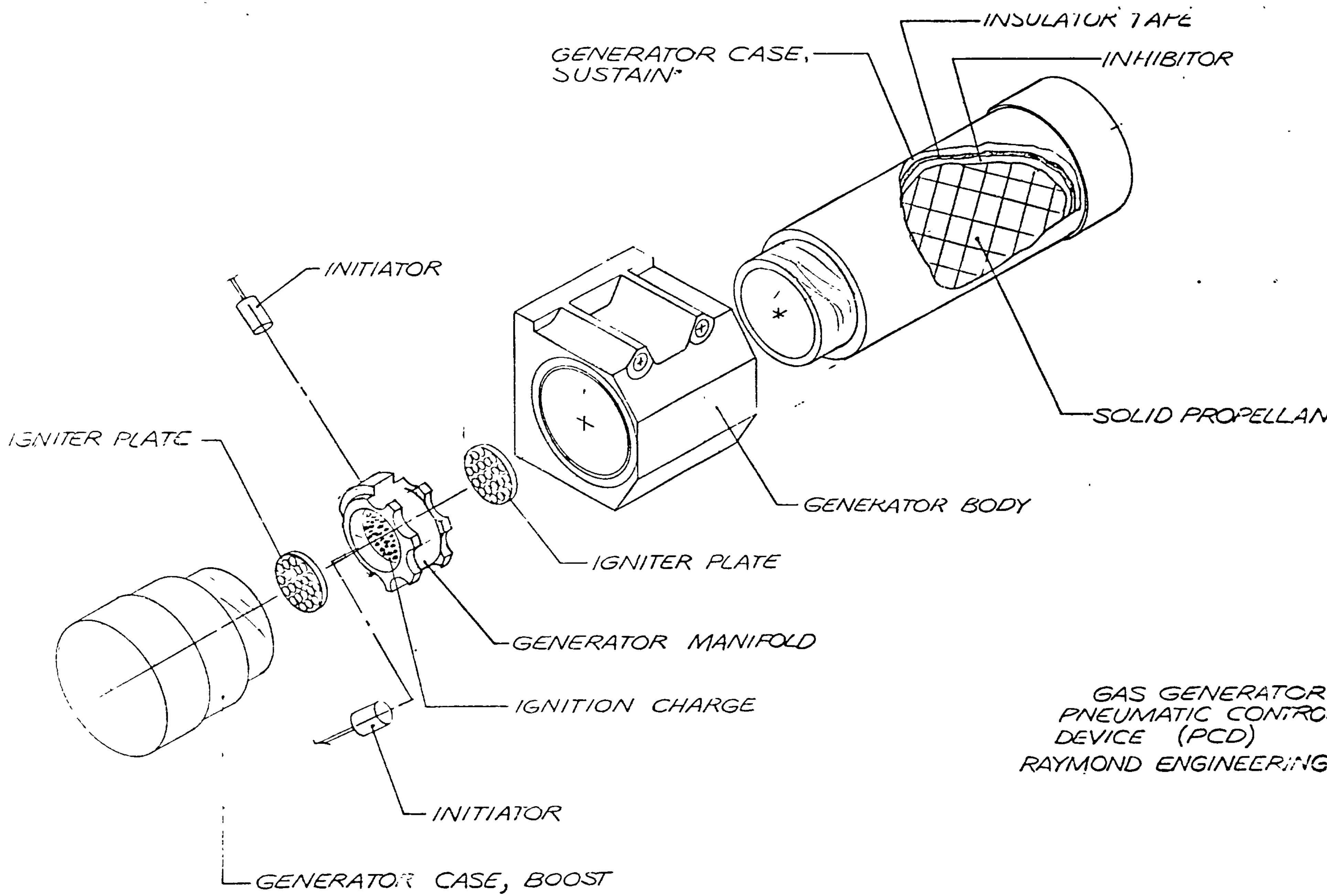

INSULATOR TAPE
INHIBITOR
GENERATOR CASE,
SUSTAIN
SOLID PROPELLAN
INITIATOR
IGNITER PLATE
GENERATOR BODY
IGNITER PLATE
GENERATOR MANIFOLD
IGNITION CHARGE
INITIATOR
GENERATOR CASE, BOOST
GAS GENERATOR
PNEUMATIC CONTRO
DEVICE (PCD)
RAYMOND ENGINEERING

FIGURE 17

These tests started with a heavy-wall breadboard generator based on a theoretical design then evolved into a prototype heavy-wall generator simulating the preliminary design configuration. Fifty-five (55) heavy-wall tests were performed to evaluate different candidates for all generator materials and to refine the generator POM design (refer to Figure 18 and Table I thru Table V).

The igniter charge and propellant burn surfaces were subjected to several modifications during these tests due to propellant ignition problems. The gas generator configuration that evolved from this evaluation will reliably ignite the propellant grains. Also during these tests several features were added to the generator design improving its performance. A closure disc was incorporated into the generator housing which provides a hermetic seal for the output port and allows the chamber pressure to reach an ignition level befor rupturing the closure disc. A mechanical catch was included in the closure disc design to restrict metal particles larger than .020 inch diameter from the closure disc rupture traveling to the nozzle. Gas filters were added to the generator chamber preventing carbonaceous particles larger than .004 inch diameter in downstream gas flow thus improving the performance of the nozzle.

The breadboard gas generator evaluation test demonstrated feasibility of the 55 second generator with five (5) second boost. During these tests the theoretical gas generator design was improved and refined t establish the POM design. The POM design hardware is shown in Figure 19 and is used in the flight configuration verification tests describe in Table VI and VII. The flight configuration gas generator test

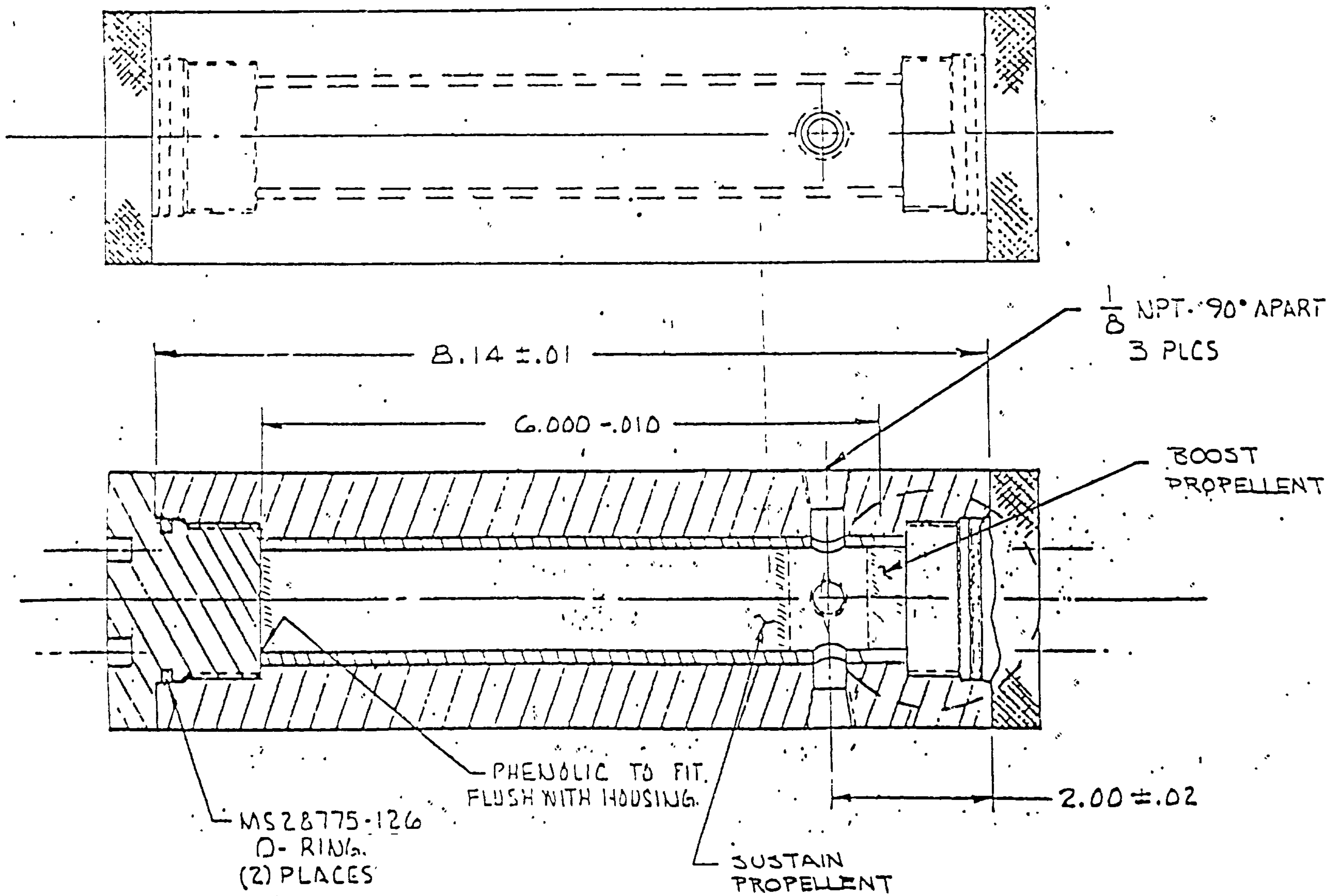
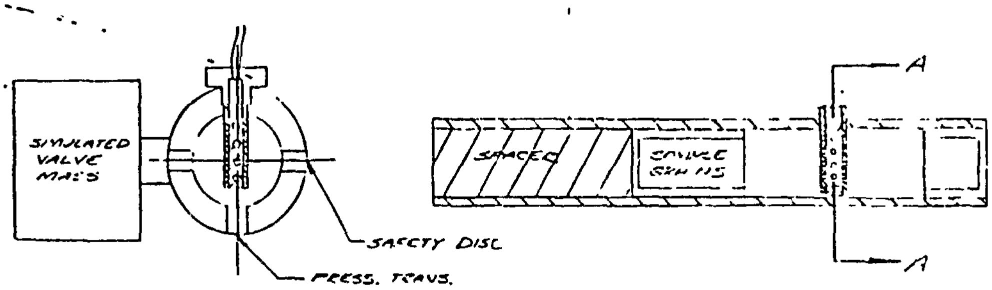


FIGURE 18 HEAVY WALL GAS GENERATOR

Heavy Wall Generator/Propellant Evaluation

Ignition Charge - To Be Determined

Propellant Grains - 1" Dia. with .050 thick inhibitor



ENLARGED VIEW A-A

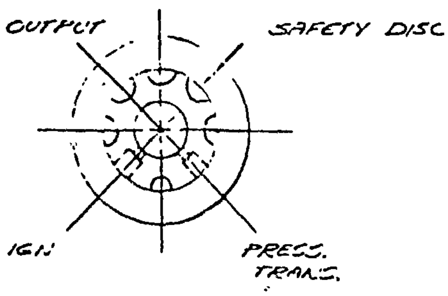
Test	Date	Log Description	Ignition Charge	Pressure (psi) Ign.	Boost	Sust.	Time (sec) Boost	Sust.	Temp. (°F) Body	Tube	Remarks
#1	8/2	T-433, 1/2"B + 1 1/2" S	.65gBKNO$_3$+.25g Prop	No	Instrumentation		~4	Stop Watch ~15	--	--	
#2	8/3	T-433, 1/2"B + 1 1/2" S	.65 " +.25g "	500			~4 1/2	15 1/2	--	--	
#3	8/3	Inert Grains	.65 " +.25g "	700	Ignitor only						
#4	8/4	T-704, 1/2"B + 1 1/2" S	.65 " +.25g "	900	> 3000	Partial Inhibitor Failure		8	--	--	
#5	8/11	T-704, 1/2"B + 1 1/2" S	.65 " +.25g "	500	1500	300/450	6 1/2	32	--	--	
#6	8/	O-453D	.65 " +.25g "								
#7	8/	O-453D	.65 " +.25g "								
#8	8/15	O-453D, 1/2"B + 1 1/2" S	.65 " +.25g "	400	1325	525/625	6	27	--	--	
#9	8/16	O-453D, 1/2"B + 1 1/2" S	.65 " +.25G "	400	1300	475/600	6 1/2	28	--	--	
#10	8/22	T-433, full grain	.65 " +.25g "	350	> 3000	A		5	--	--	
#11	9/16	T-704, 1/2"B + 41/2 S (B)	.65 " +.45 "	525	Clipping > 1950	550/675	13	61	<500	~1350	
#12	9/19	O-453D, 1/2B + 2" S (B)	.65 " +.45 "	425/300 C	~3000	1850/2150	5	20	<500	~1250	
30 Sept.		Inert Grains (B)	.65 " +.5 "	250	Ignitor Only-Closure Did Not Rupture-Leakage By Adhesive 910						
30 Sept.		T-433, 1/2B + 3 3/4 S (E)	.65 " +.5 "	450 (D)	1950	950/1050	6	45	<500	~1350	
3 Oct.		Inert Grains (B)	.65 " +.5 "	125	Igniter only - closure did not rupture						
3 Oct.		Inert Grains (B) (B)	.65 " +.5 "	100	Igniter only - closure did not rupture (2) .002 Discs						
5 Oct.		Inert Grains	1.0" " —	450	Igniter only - closed volume - Plugged						
6 Oct.		Inert Grains	2.0 " —	950	Igniter only - closed volume - Plugged						
7 Oct		T-433, 1/2B + 3 3/4 S (D)	2.0 " —	900	>3000	Inhibitor failure		25	<500	~1450	
10 Oct.		T-433, 1/2B + 3 3/4 S (F)	1.0" + 1.0 "	1375	>3000	Two Explosions - apparent nozzle blockage					

NOTES:
(A) Transducer failed to hold pressure - blow apart - pipe plugs were 1/4 NPT (.002 Brass shim stock, over .208 hole - scribed with X)
(B) Closure Disc added to end of nipple between Valve Body & Heavy wall.
(C) Orifice .020 before/.0205 after.
(D) Orifice .0210 before/.0215 after.
(F) Closure Disc .004 Brass over .208 thru hole of nipple - Brass scored.

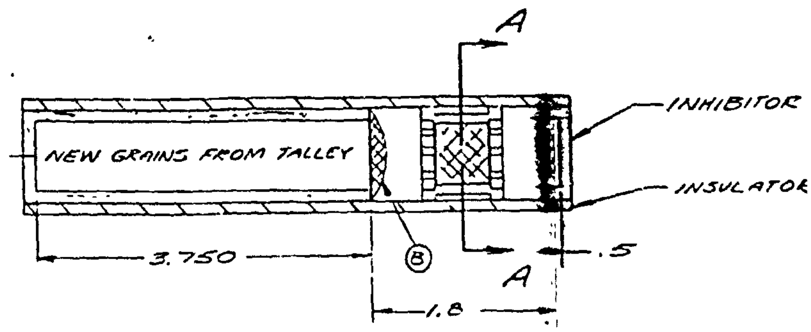
TABLE I

Revised Heavy Wall Igniter Configuration/Straight Grain

Closure Disc - .005 Brass Over .208 Through Nipple
Ignition Charge - Must Determine Due to Larger Volume ~ 2in^3
Propellant Grains - 1" dia. Tal.-433/.070 Inhibitor



ENLARGED VIEW A-A



Date	Log Test Description	Pressure (psi) Ignition	Boost	Sustain	Time (sec) Boost	Sustain	Temp (°F) Tube	Remarks
24 Oct	.5gBKNO$_3$+.25gT-433 Inert Grains	<100		Closure did not rupture				
24 Oct	.75gBKNO$_3$+.25gT-433 Inert Grains	200		"	" "	"		
25 Oct	.75gBKNO$_3$+.5gT-433 Inert Grains	200		"	" "	"		
25 Oct	1.5gBKNO$_3$ with mylar tape, Inert Grains (A)	300		"	" "	"		
27 Oct	1.5gBKNO$_3$ Basket, Inert Grains (A) (B)	1100		"	" "	"		
28 Oct	(A) Full Grain/(B) 3g BKNO$_3$-Nozzle Blocked	1425	Closure rupture @ 2000 psi & safety rupture @ 3.2 sec. >3000 psi					
31 Oct	(D) Full Grain/(B) (C) 3g BKNO$_3$-Nozzle Blocked	1150	Safety rupture @ 2.5 sec. >3000					
1 Nov	Full Grain/(B) (C) 3g BKNO$_3$-No Closure	850	1500	700	7	51	~1350	
7 Nov	(D) (E) Full Grain/(B) (C) 3g BKNO$_3$-Nozzle Blocked	1050	>3000	Safety rupture at 3.8 sec				

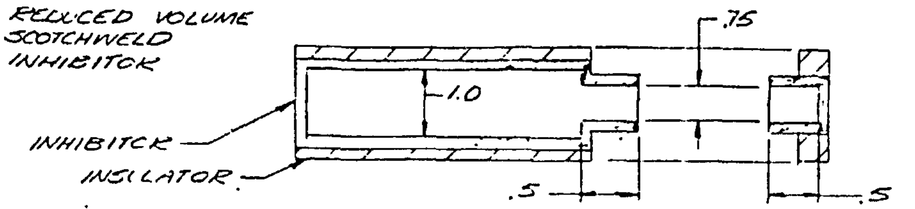
NOTES:
- (A) Closure changed to .004 Brass Disc
- (B) Add .75g BKNO$_3$ to each grain surface held with cellophane tape
- (C) Use paper instead of cellophane and mylar tape
- (D) Use .002 Brass Closure Disc
- (E) Use mechanical catch for closure (TRAP)

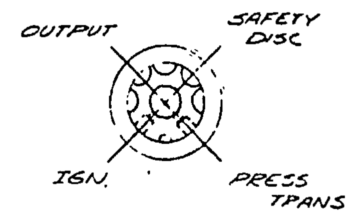
TABLE II

PII GAS GENERATOR TESTS

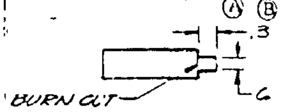
Reduced Grain Configuration/Heavy Wall

Closure Disc - .005 Brass - Scored/.10 dia hole of trap
Ignition Charge - 1.5 gm BKNO3
Propellant Grains - 1" dia Tal-433/.070 inhibitor





Heavy Wall Test Equipment/POM Configuration

Date	Log Test Description	Pressure (psi) Ignition	Boost	Sustain	Time (sec) Boost	Sustain	Temp (sec) Body	Tube	Remarks
15 Nov	Misfire-no oven cure	700							
16 Nov	Misfire	875							
16 Nov	Misfire-did not rupture disc	600							
17 Nov	Igniter only A	400							
17 Nov	Burn out-closure .005 + .002 disc held A	450	>3000	Safety Disc Blow @ 4 1/2 sec					
18 Nov	Igniter only A B	900							
19 Nov	Burnout A B	900	>3000	Closure Disc Rupture @ 3 1/2 sec					
21 Nov	Burnout A B	850	>3000	Closure Rupture @ 2 1/2 sec					
2 Dec	100 Micron Filter Transition Failure A B C 	600	1150	500	2 1/2	8	<500	~1350	
3 Dec	High Boost ~4000 psi) A B C	750	>3000	375/775	3	57	<500	~1350	

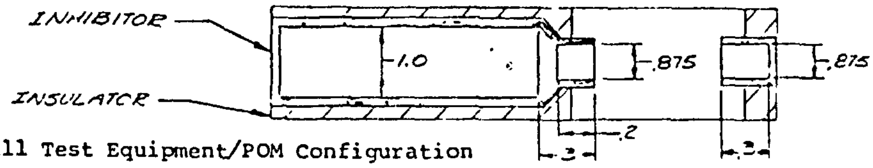
NOTES: A Igniter changed to .75gm $BKNO_3$ & .8gm T-433
B Closure disc changed to .004 Brass
C Sustain Grain change to .6 dia x .3 long reduction

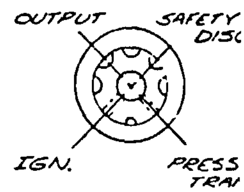
TABLE III

PII GAS GENERATOR TESTS

Tapper Configuration/Heavy Wall

Closure Disc - .004 Brass Full Hard - scored with .1 dia punch/trap
Ignition Charge - 0.8 gm 1/8" cubes
0.35 gm fine shavings N-5 Propellant
Nozzle - .0225 Plug
Filters - 100 Micron, SS 302
Propellant Grains: 1" dia. Tal-433 with .070 inhibitor





Heavy Wall Test Equipment/POM Configuration

	Log	Chamber Pressure (psi)			Time (sec)		Temp (°F)		
Date	Test Description	Ignition	Boost	Sustain	Boost	Sustain	Body	Tube	Remarks
5 Dec	40 Filter - Slight leak @ Ig plug	575	>3000	900/>3000	3	37	<500	~1350	
5 Dec	Igniter only - disc held	950							
7 Dec	Misfire - Disc did not rupture	~300 *							
7 Dec	Misfire - Disc did not rupture	325 *							
7 Dec	Disc Rupture >3000 psi - Nozzle transducer-.002 1/2 H Brass Disc	500	475/>3000	350/650	3	61 1/2	<500	~1350	
8 Dec	Igniter only - .001 Full Hard Disc	1125 A	Brass Disc ruptured at 1125 psi						
8 Dec	Visicorder stopped at 2 sec	900/2000	Rupture @ 2000 psi			stop watch 64	<500	~1350	
12 Dec	Misfire	850/1075	Brass Disc ruptured at 1075 psi						

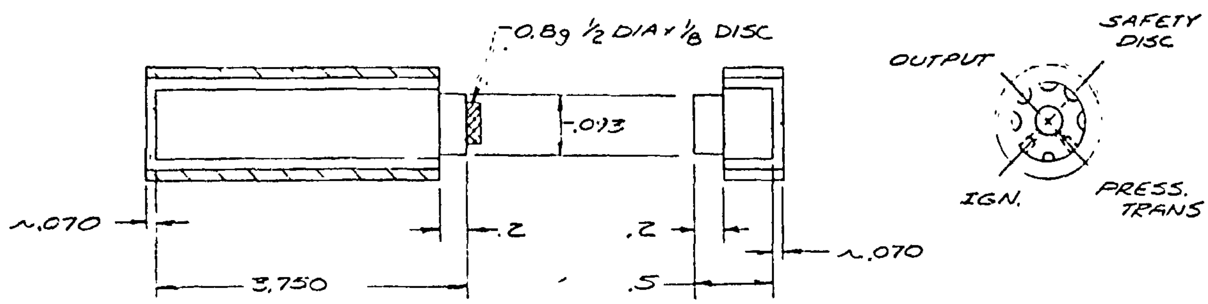
NOTES: * Low Igniter Pressure at 0°F Test temp - Add .005 Teflon closure disc in igniter basket instead of paper disc for all test to follow - also Nozzle Transducer

A Ignition Load changed to 1.0 gm 1/8" cubes
0.5 gm fine chips

TABLE IV

Step Configuration/Heavy Wall

Closure Disc: .001 Brass Full Hard/Stiffener ring & trap/.10 dia hole
Ignition Charge: 0.5 g fine chips — N-5 double-base propellant
1.0 g 1/8" cubes — .005 TFE IGN Closure
0.8 g 1/2" dia x 1/8 disc
Filters: 100 micron, SS 302
Propellant Grains: 1" dia plus .070 Inhibitor, T-433



Heavy Wall Test Equipment/POM Configuration:

LOG		Chamber Pressure (psi)			Time (sec)		Temp (^oF)		
Date	Test Description	Ignition	Boost	Sustain	Boost	Sustain	Body	Tube	Remarks
13 Dec	Heavy Wall-Visicorder stopped after 34 sec	1250	750/1450	525/850	<5	~61	<500 F	~1350°F	
13 Dec	Heavy Wall-Visicorder	1150	675/1325	400/825	<5	62 1/2	<500 F	~1350	
14 Dec	Heavy Wall-No Propellant Burn			M I S	F I R E				
16 Dec	Heavy Wall-3 1/2" Sustain - reused	1750	800/~3500 ⊛	575/725	<5	43 1/2	<500	~1350	
15 Dec	Heavy Wall-Output Tube Mis-assembled	1550	800/~4000 Ⓑ	600/650	~12 Ⓑ	47 1/2	<500	~1350	
27 Dec	Heavy Wall-3" Sustain - Re-use T-200 Ⓐ	750	650/2200 ⊛	1450/1750 ⊛	<5	32 1/2	<500	~1350	
28 Dec	Heavy Wall-3" Sustain - Re-used T-200 Ⓐ	500 Ⓒ	750/1100	550/650	<6	43 1/2	<500	~1350	
29 Dec	Heavy Wall-3" Sustain - Re-used T-200 Ⓐ	600 Ⓒ	700/1150	525/625	<6.5	47	<500	~1350	

NOTES: ⊛ Intermittent Nozzle blockage
Ⓐ Change 1/2" dia. x 1/8" lg. disc of N-5 bonded to grain to Tal-200
Ⓑ Excessive Nozzle blockage due to output connected to pressure part which bypasses filters.
Ⓒ Questionable Pressure Transducer (voltage?)

TABLE V

setup as shown in Figure 20 consists of a all up gas generator connected to the PCD control valve. A test port in the top of the generator housing provided a pressure tap and a safety rupture disc attachment. The control valve output plate connected to a twenty (20) inch transfer tube to the gas flow nozzle. Just up stream of the nozzle was a test port for a pressure transducer and a gas stream thermocouple probe.

During the flight configuration verification tests several problems occurred which related to adequate sealing of the flight hardware at the electrical interface. Several potting materials were evaluated before a suitable one was found. The squib initiators were redesigned in a threaded adapter to allow a mechanical pressure seal during operation by minimizing the leak path and use of a ceramic adhesive. The closure disc was reworked to incorporate a threaded assembly to provide more consistent performance for ignition pressure rupture. Filter material was changed from stainless steel to inconel to optimize its performance under chamber temperature conditions. The igniter disc attached to the sustain grain surface was removed and incorporated into a redesigned igniter basket to provide an improved ignition and a more uniform propellant grain burn surface (Refer to Table VI).

The redesigned flight configuration was tested, refer to Table VII, and proved to have repeatable results. The last (12) tests were a series, requested by ARRADCOM, of hot, cold and ambient firings. The results of these tests can best be described by gas horsepower curves as compared to the required limits indicated as dashed lines,

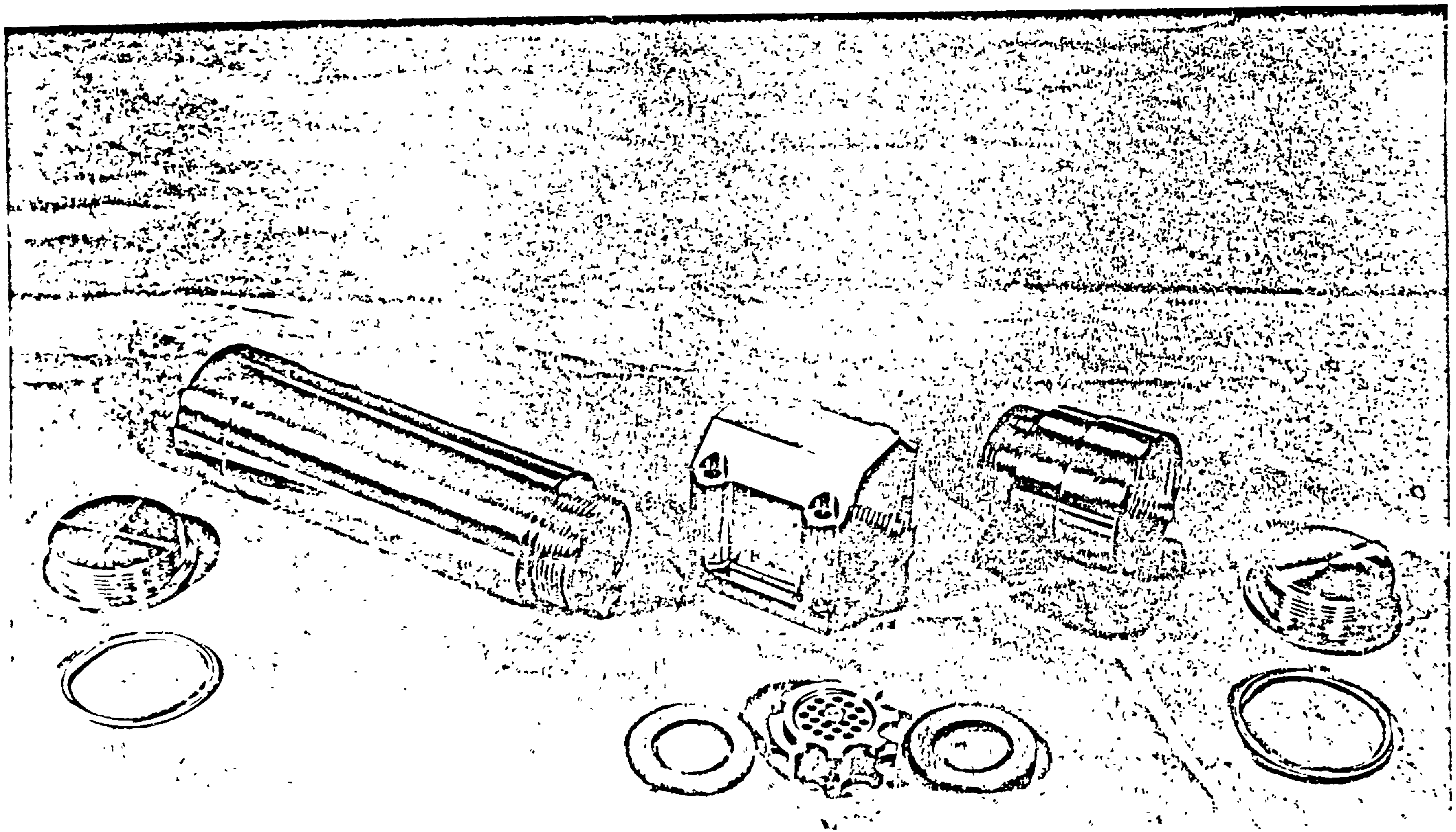


FIGURE 19   POM GAS GENERATOR

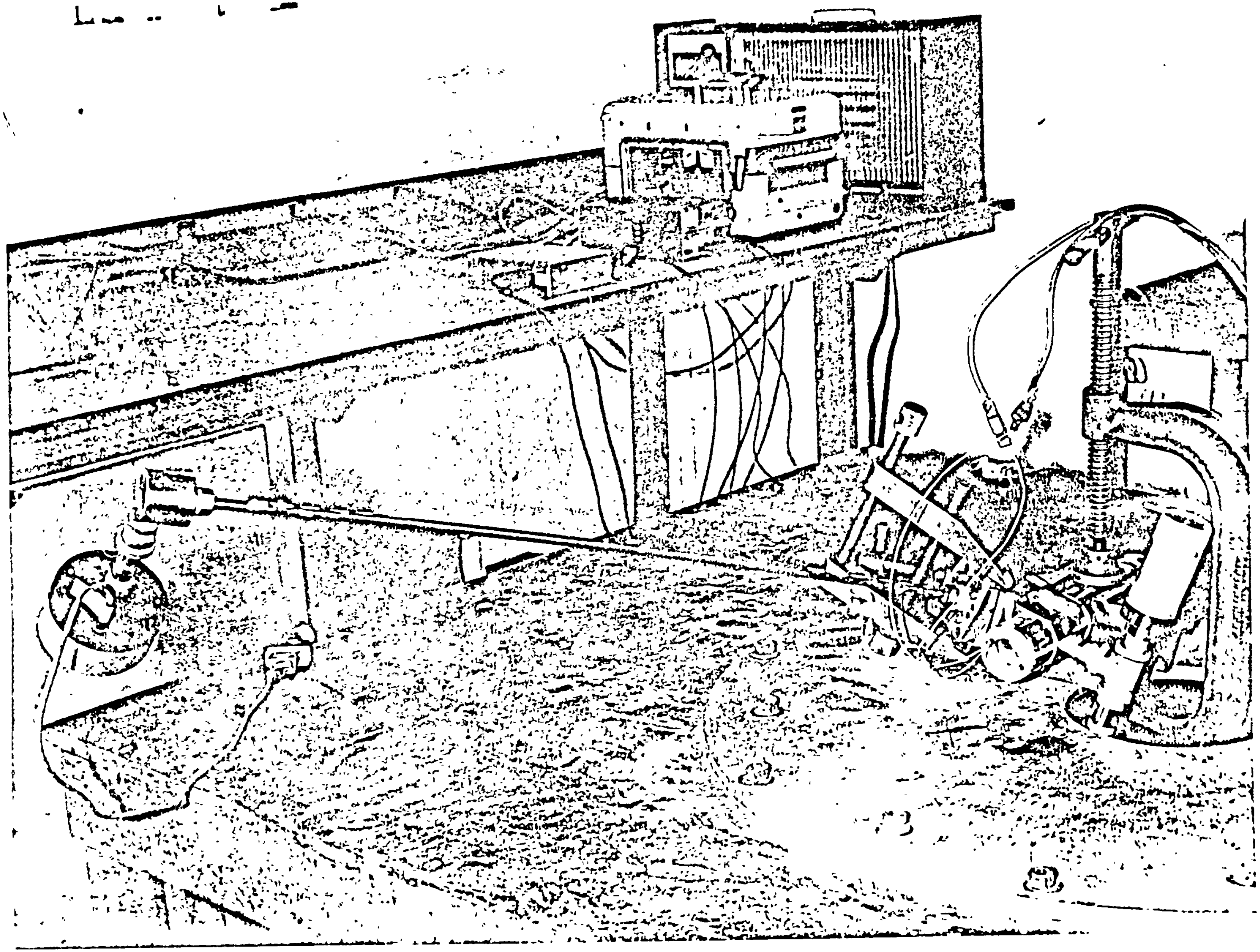


FIGURE 20 POM GENERATOR TEST STAND

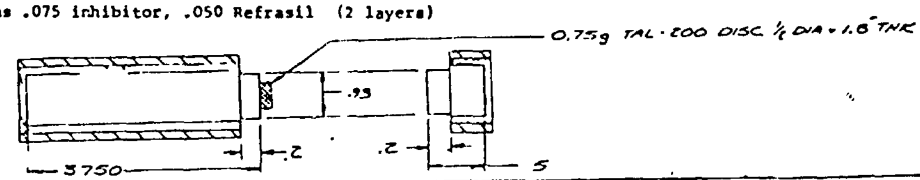
Flight Configuration - Thin Wall

Closure Disc - .001 Full Brass/stiffener ring and trap/.10 dia hole
Ignition Charge - 0.5g fine chips
1.0g 1/8" cubes
0.75g Tal-200 Disc
1/2" dia x 1.8" thk

N-5 in basket with .005
TFE Closure Disc

Filters - 100 Micron, SS 302

Propellant, T-433, 1" dia plus .075 inhibitor, .050 Refrasil (2 layers)



Date	Test Description	Pressure (psi) Ignition	Pressure (psi) Boost	Pressure (psi) Sustain	Time (sec) Boost	Time (sec) Sustain	Temp (°F) Body	Temp (°F) Tube	Remarks
30 Dec	Misfire - no potting								
3 Jan	A39 Potting 1/2 full failed	1100	925/1625	550	< 5	11 G	<500	~1350	
6 Jan	Plastic Porcelain 3/4 - 1/4 A39 Potting - slight leak	2350 A	1075/1700	450/625	< 5	57	<500	~1350	
11 Jan	A2 - Set Scr behind Initiator failed	~ 3100 A	875/1400	550/700	5	29 G	<500	~1350	
13 Jan	Misfire - Sylgard 184 Initiator adapter G grain (sustainer) moved	2350 A	~ 1/2 sec - pressure differential caused burn out						
17 Jan	A2 - Iniator Thd., adaptor - Misfire	1125	Valve ball mis-assembled to position venting seat						
19 Jan	A2 - Iniator Thd. Adaptor Visicorder stopped at 44 sec. Modify orifice to Nozzle	2100	1125/1325	475/675 @ 44 sec	<5	stop watch 57	<500	~1350	
23 Jan	A2 - Iniator Thd. Adaptor Nozzle plugged/grain moved	> 3000 A	5 1/2 sec - pressure differential caused burn out						
9 Feb	A2 - Iniator Thd. Adaptor Ignition charge only *	925	Change propellant process - grind and cut						
9 Feb	A2 - Iniator Thd. Adaptor Ignition Charge Only *	975	Change propellant process - grind and cut						
10 Feb	A2 - Iniator Thd. Adaptor Ignition Charge Only *	1200	Change propellant process - grind and cut						
13 Feb	A2 - Iniator Thd. Adaptor New Closure disc and trap G	1150	675/1200	350/450	5 1/2	70	350/400°F B/S	~1350°F	
14 Feb	A2 - Iniator Thd. Adaptor New Closure disc and trap Inconel Filter	1300	725/1275	475/625	5	potting blow out 59	400/450°F B/S	~1350°F	
15 Feb	A2 - Iniator Thd. Adaptor New Closure disc and trap Inconel Filter	1150	525/1050	375/575	5	65	400/500°F B/S	~1350°F	
15 Feb	A2 - Iniator Thd. Adaptor New Closure disc and trap Inconel Filter	1275	450/1200	425/600	7	61	400/450°F B/S	~1350°F	
16 Feb	A2 - Iniator Thd. Adaptor New Closure disc and trap Inconel Filter - misfire	1325	~ 1/4 sec - pressure differential caused grain to move - adhere grain to end cap - eliminate boot						
21 Feb	3M Potting - New Closure disc and trap - Inconel Filter Potting Leak	no disc	500/1150	400/550	8	64	450/500°F B/S	~1350°F	
22 Feb	3M Potting - New Closure disc and trap - Inconel Filter Potting Leak	1275	175/950	425/575	10	62	400/400°F B/S	~1350°F	
24 Feb	A2 Potting B - New Closure disc and trap - Inconel Filter - (2) T-200 disc's	1000/1550	975/1250	350/425	5 1/2	partial grain 47	400/400 B/S	~1350°F	

NOTES: G Potting failed to hold pressure in chamber through initiator holes which extinguished grain as it vented

A Excessive Ignition pressure due to closure assembly - rework Interface to maximize shear

B Potting leak traced with die penetrent to glass to metal initiator seal

TABLE VI

[illegible]

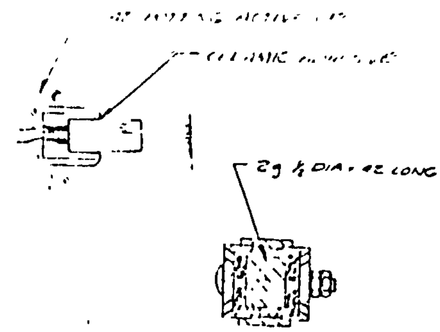
Redesign Flight Configuration
Initiator bonded inside threaded plug
Ignition Charge: 2 g 1/2 dia x .42 long

.5 g fine chips

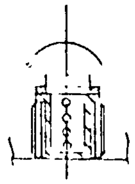
.5 g 1/8" cubes

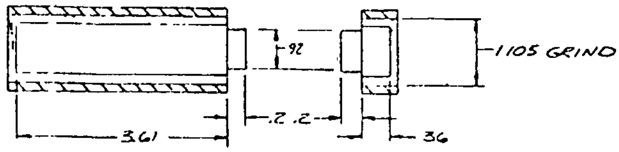
Propellant (T-433): 1" dia plus .050 inhibitor & .075 insulator
Filters - 100 micron, Inconel (.093 thk)

Closure Disc/Trap - .001 full hard Brass over .10 hole trap with (47) .020 holes



CLOSURE DISC
TRAP





Date	Test Description	Chamber Pressure (psi) Ignition	Boost	Sustain	Time (sec) Boost	Sustain	Temp Paint (°F) Body	Tube	Remarks
28 Feb	Partial Grain 2 3/4" lg Nozzle .0250 inch dia	650/1450	925/1025	350/375	6	50	400/450	1350	
1 Mar	Partial Grain 3 1/8" lg Nozzle .0225 inch dia	700/1525	1150/1625	650/750	5	43	350/450	~1350	
3 Mar	Partial Grain 3 1/4" lg Nozzle .0232 inch dia (A)	500/1150	850/1275	500/650	5	50	400/500	1350	
3 Mar	Partial Grain 3 3/8" lg Nozzle .023 inch dia (A) (B)	575/1150	900/1475	525/750	5	50	400/450	1350	
9 Mar	Full Grain-.023 Nozzle (A) (B) (D)	1250/1250	900/1150	425/675	6	61	400/450	~1350	
10 Mar	Full Grain-.023 Nozzle (A) (B) (D)	1125/1225	1100/1275	500/650	5 1/2	59	400/450	1350	
10 Mar	Full Grain-.023 Nozzle (A) (C) (D)	1050/1350	1050/1200	475/625	5	61	450/500	1350	
14 Mar	HOT Full Grain-.023 Nozzle A D (*)	1225/1375	1250/1650	600/700	4 1/2	50	450/500	1350	
17 Mar	COLD Full Grain-.023 Nozzle (A) D	1300/850	650/975	375/550	7	71	350/450	1350	
29 Mar	Full Grain-.023 Nozzle (A) (D)	1225/1175	925/	Thermocouple added-gross potting leak through 450°					
#1 5 Apr	Gov't Test (A) D (G) 325°F @ 57, 425°F @ 3	1050/1300	1100/1500	525/700	5	57	400	1450/1300	
#2 6 Apr	Gov't Test (A) (D) (E) G 904°F @ 47	1250/1750	1300/~1750 (G)	600/750	5	58	400/450	1350/1300	
#3 15 May	Gov't Test (A) (D) (H) 993°F @ 54 (2 initiators)	900/1200	950/1400	550/650	5 1/2	58	400/450	1450/1350	
#4 18 May	Gov't COLD Test (A) (D) (H) 1020°F @ 60	1150/1000	650/1125	430/650	7	67	300/350	~1350	
#5 19 May	Gov't COLD Test (A) (D) (H) 950°F @ 55	1200/725	625/975	400/575	7	71 1/2	300/350	~1350	
#6 19 May	Gov't COLD Test (A) (D) (H) 725°F @ 65 (2 initiators)	1100/900	775/1175	450/675	7	67	400/450		
#7 25 May	Gov't HOT Test (A) (D) (G) 1128 @ 35	900/1350	1175/1650	650/725	4 1/2	50	400/400	1150	
#8 25 May	Gov't HOT Test (A) (D) (G) 958 @ 55	1275/1225 (I)	975/1200	420/575	4 1/2	58 (I)	400/450	1050	
#9 26 May	Gov't HOT Test (A) (D) (G) 1022 @ 50	900/1350	1100/1600	530/720	4 3/4	55	400/450	950	
#10 21 Jun	Gov't Test (A) (D) (G) 886 @ 45	1225/1125	1025/1525	550/600	5	61 (I)	400/450	950	

NOTES:
- (A) Inhibitor added to ID of 2 g T-200 slug - over threads
- (B) A-2 potting leakage after 45 sec
- (C) Dualco 460 potting - large leakage after 43 sec.
- (D) Open Ign basket holes from .062 to .093 dia
- (E) Thermocouple ground to transducer by ionized gas
- (F) Partial Grain
- (G) Thermocouple grounded Junc.
- (H) Thermocouple exposed Junc.
- (I) Potting leak traced with dye penetrant to initiator sub-assembly (ceramic bond line and adapter thread leakage)

TABLE VII

[illegible] to Figures 21 through 26. The low gas horsepower in the beginning of the sustain phase during cold tests, the high gas horsepower in the boost during hot tests and the gradual increase of gas horsepower during the sustain phase are all correctable conditions by tailoring the POM design. At this stage of development the gas generator has demonstrated feasibility and indicated the stated requirements could be attained. The POM gas generator will require modifications in the next contract phase tailoring the design to produce the required gas horsepower profile. Since the actual gas horsepower required to operate the Garrett turboalternator might change the design requirements, the gas generator/turboalternator compatibility tests will further define the required Phase II design for the gas generator.

Compatibility tests were carried out in accordance with the prescribed test plan using the Garrett POM turboalternator and the Raymond POM gas generator. The test sequence, procedures and results are discussed in Appendix G. This test series was successful in that it demonstrated compatibility at hot and ambient temperatures, however, at cold temperature conditions it produced unusually lower gas horsepower profiles and longer burn times than had been experienced at any previous test. A study was initiated to analyze the cold temperature gas generator anomaly. This analysis, refer to Appendix H, identified heat losses as the probable cause for the cold temperature variation in performance at Garrett. A verification test plan was proposed and approved to evaluate this possibility. These tests are to be run during Phase II of the Pershing II gas generator development contract. The data generated from these tests will be used to formulate design modifications of the present gas generator that will correct the cold temperature anomaly.

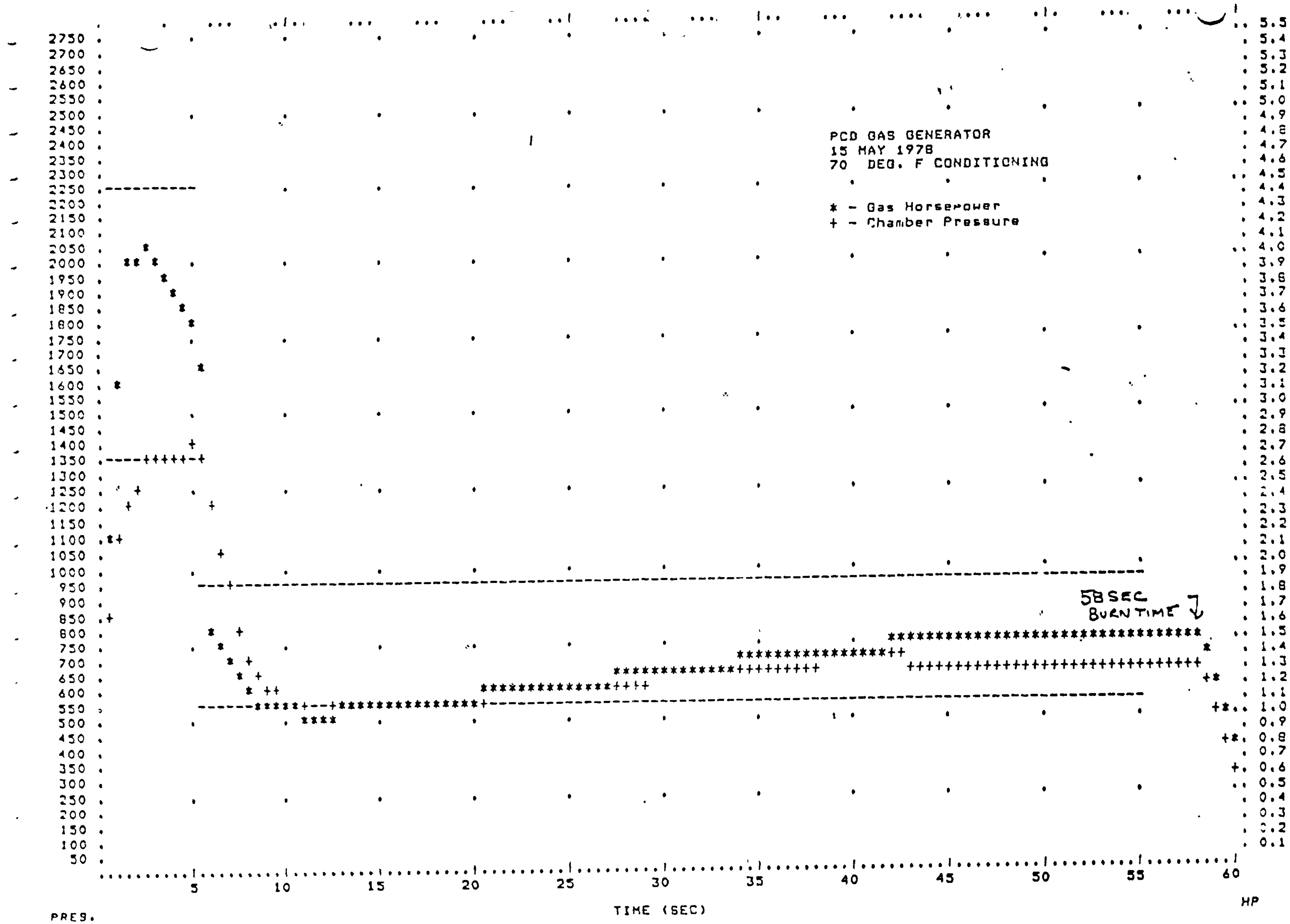

PCD GAS GENERATOR
15 MAY 1978
70 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
58 SEC
BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 21

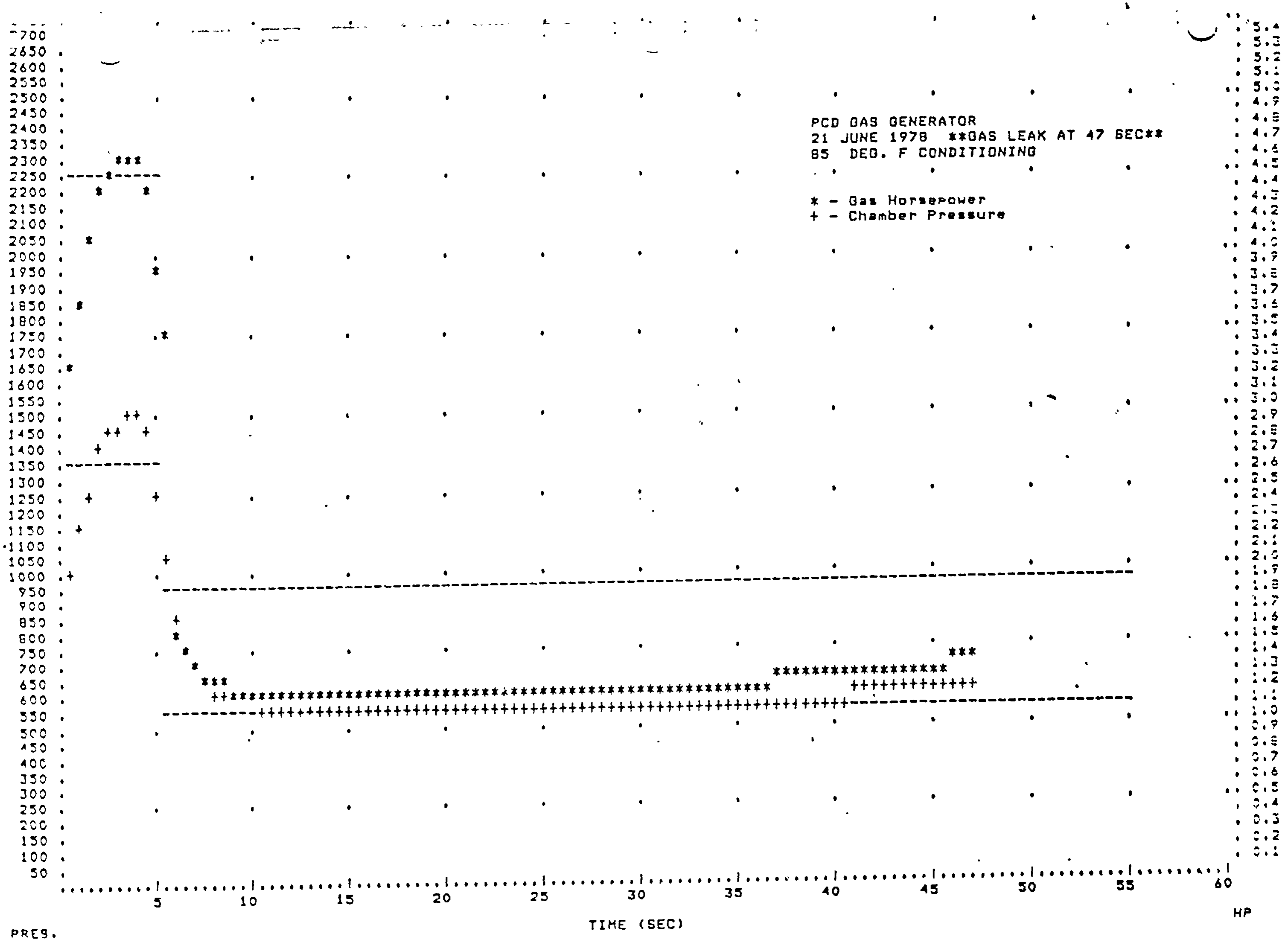

PCD GAS GENERATOR
21 JUNE 1978 **GAS LEAK AT 47 SEC**
85 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 22

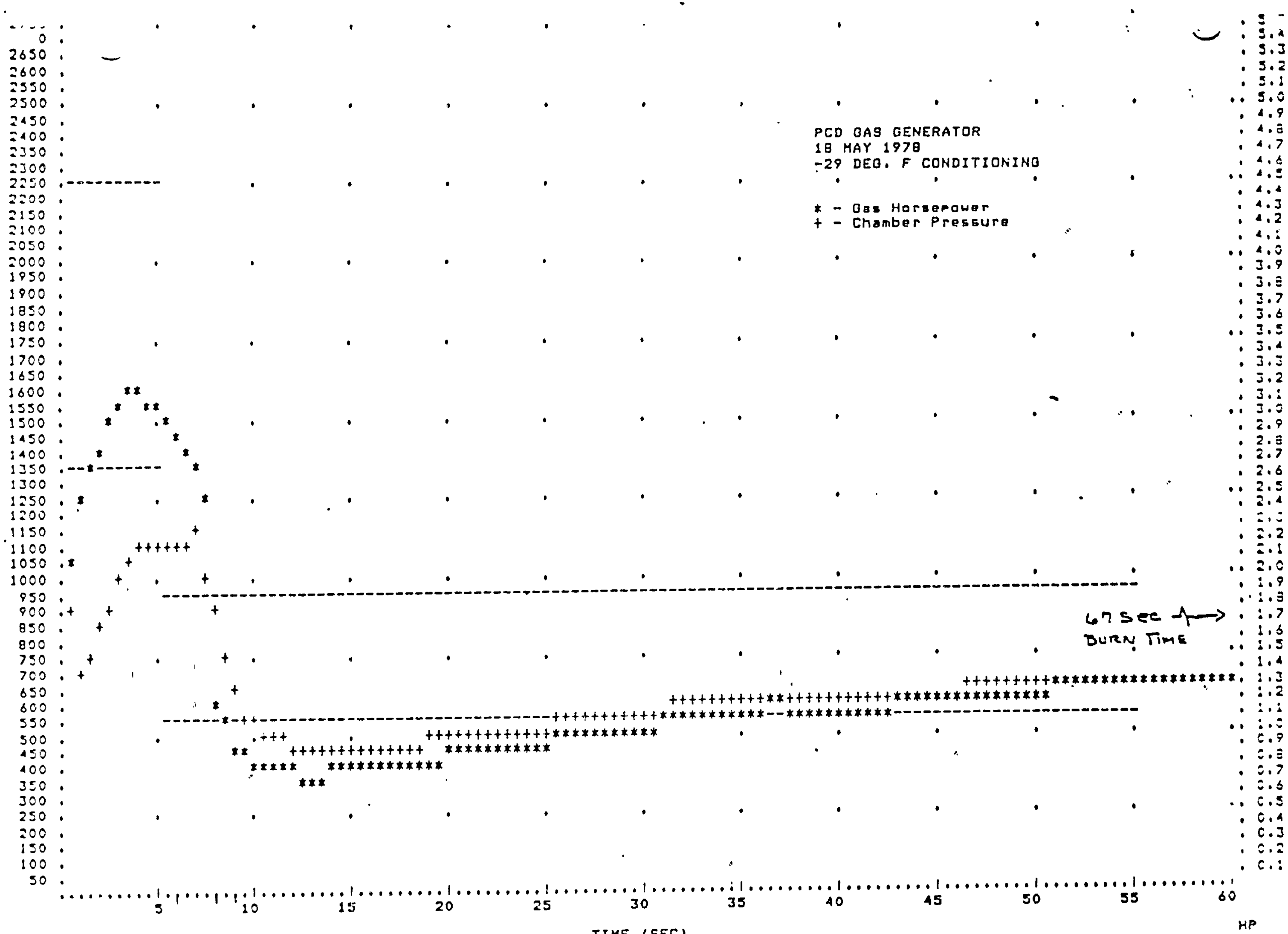

PCD GAS GENERATOR
18 MAY 1978
-29 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
67 sec
BURN TIME
TIME (SEC)
PRES.
HP

FIGURE 23

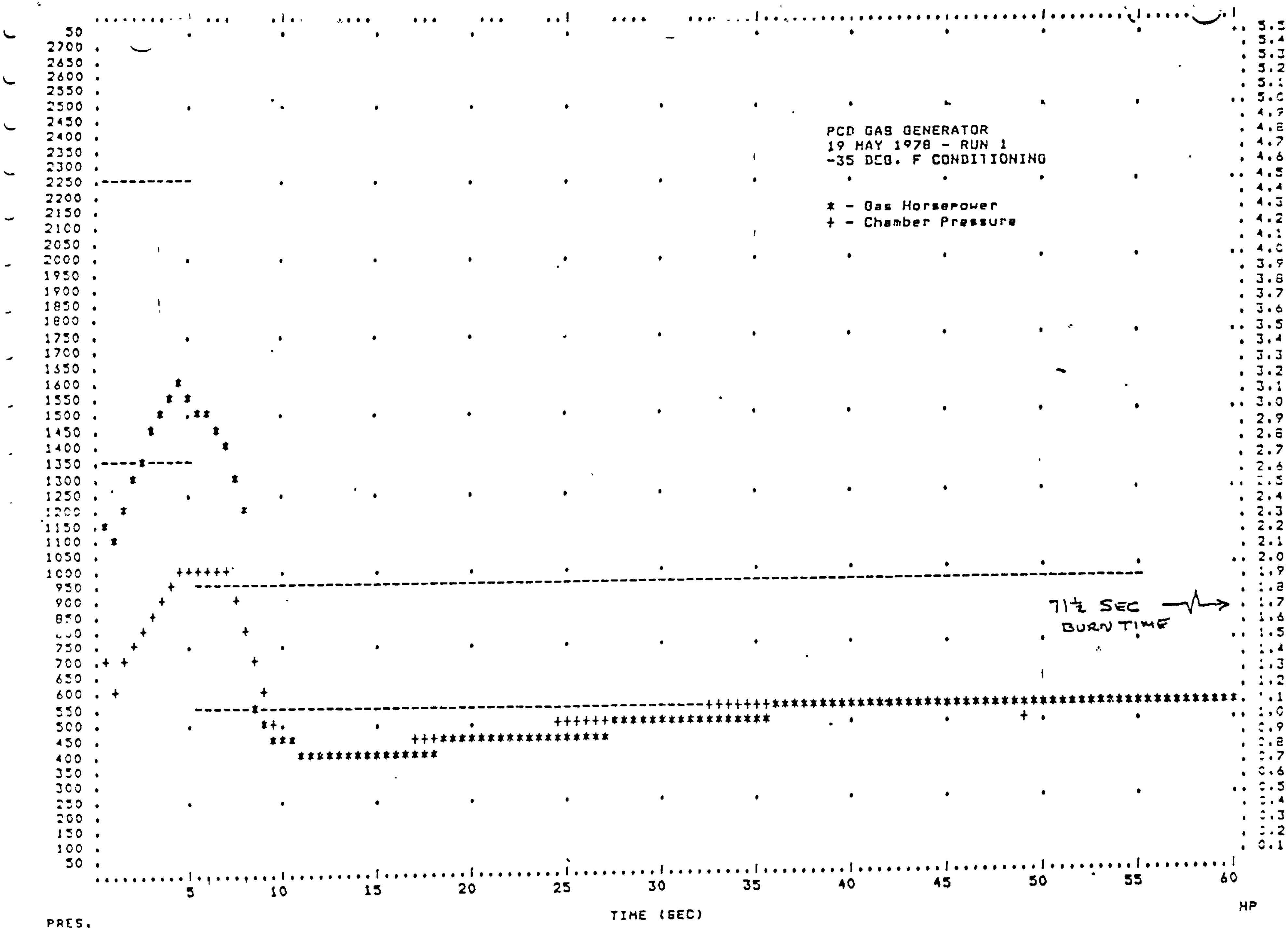

PCD GAS GENERATOR
19 MAY 1978 - RUN 1
-35 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
7½ SEC
BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 24

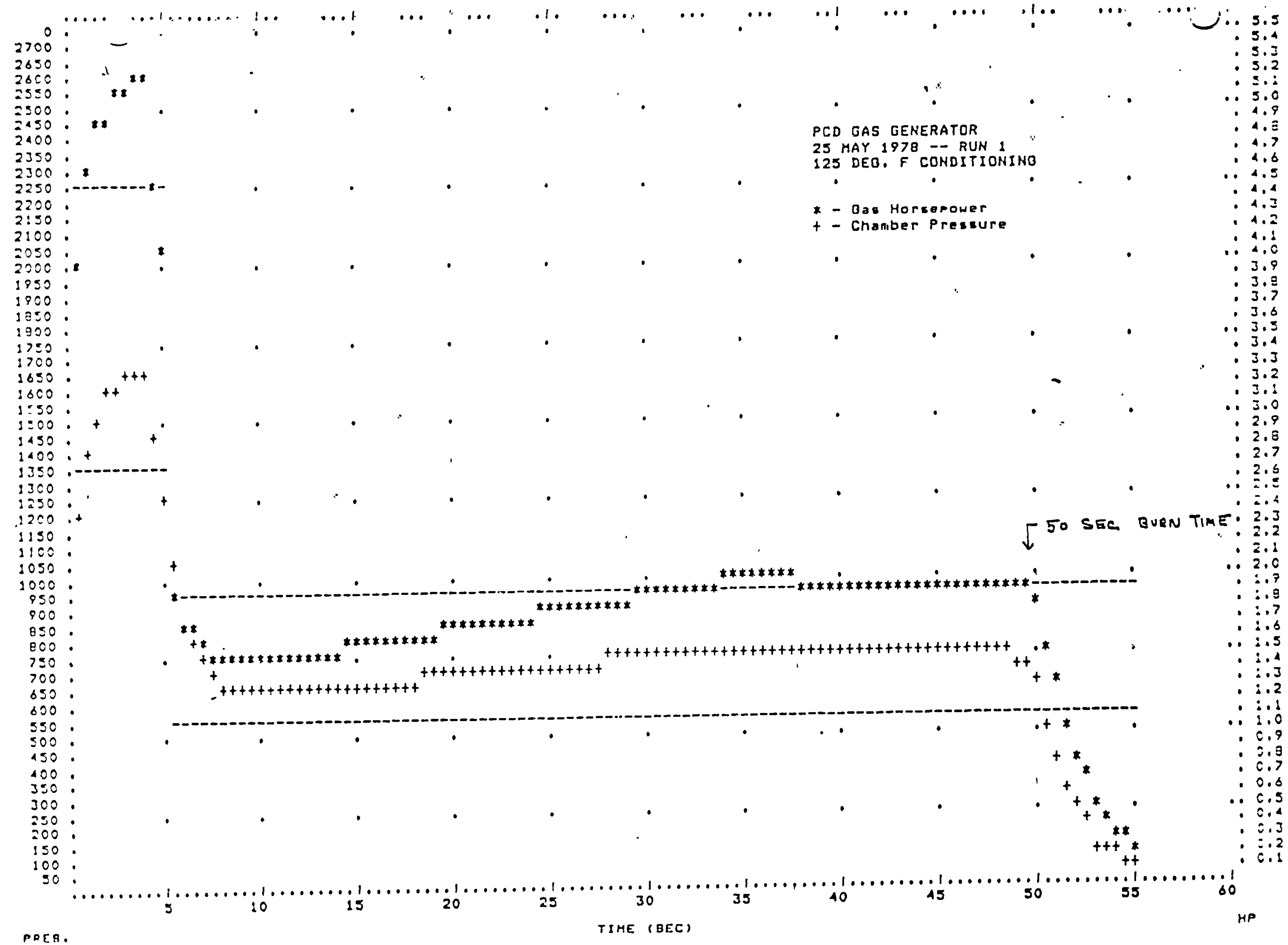
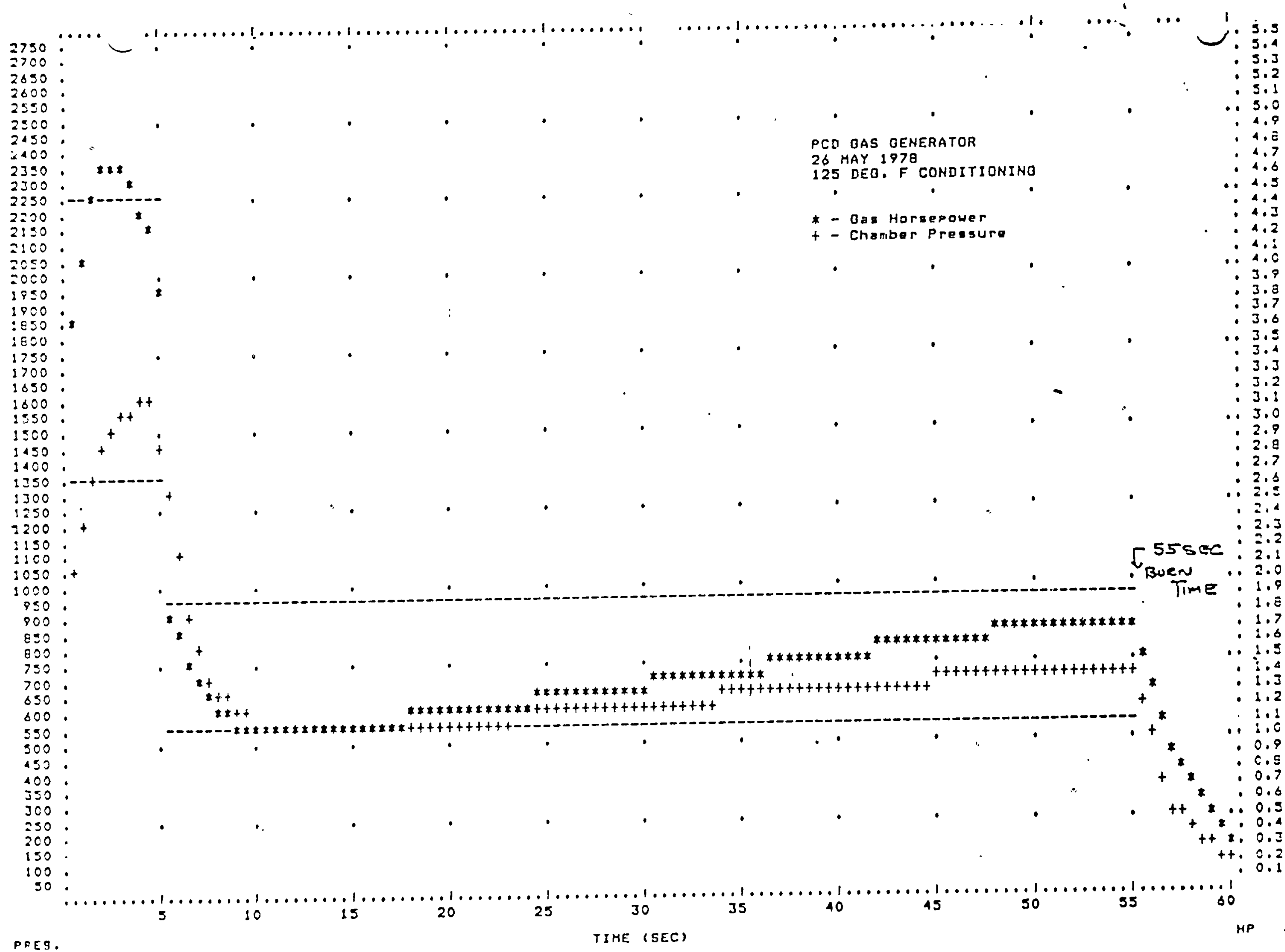

PCD GAS GENERATOR
25 MAY 1978 -- RUN 1
125 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
50 SEC BURN TIME
TIME (SEC)
PRES.
HP

FIGURE 25



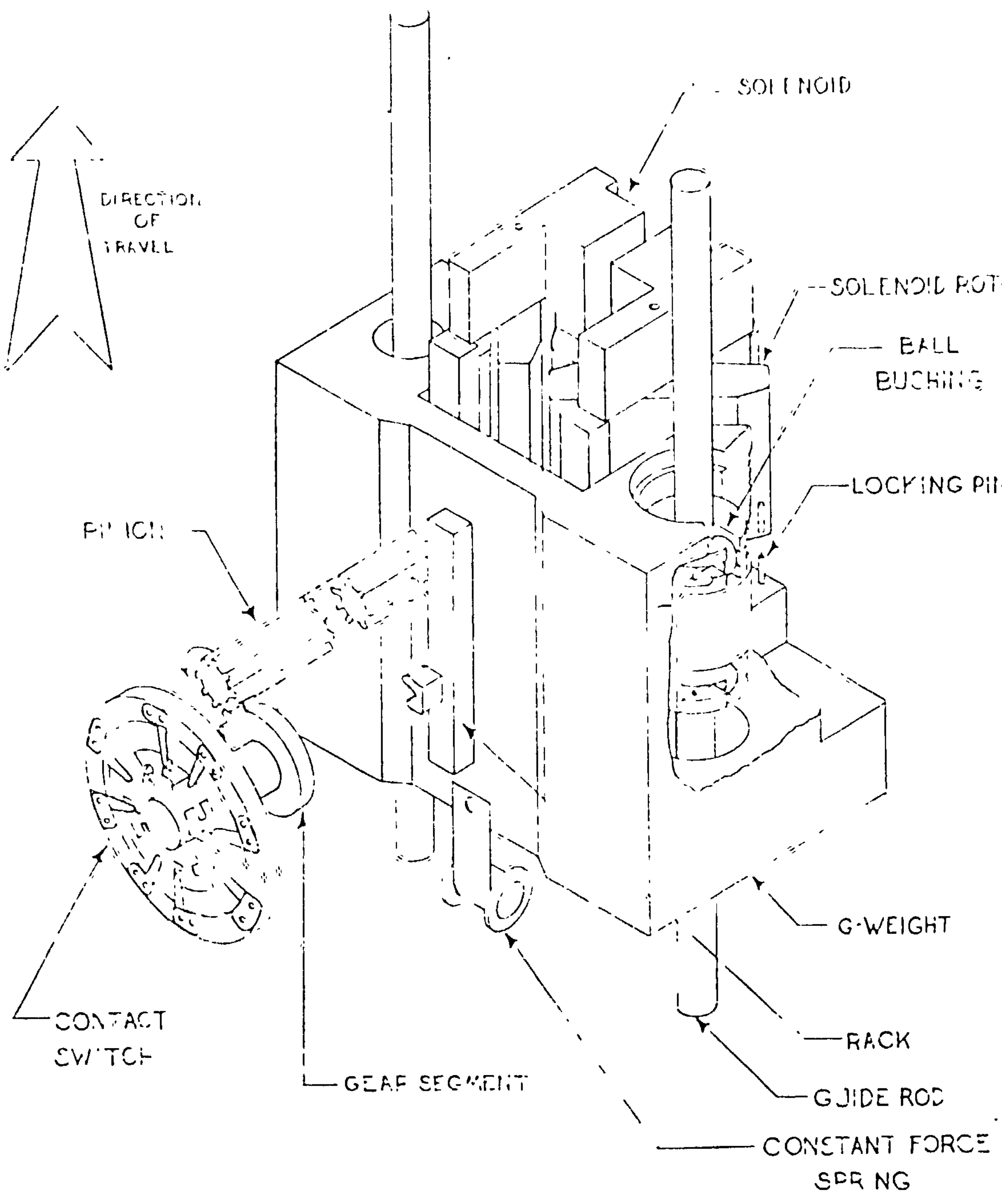
PCD GAS GENERATOR
26 MAY 1978
125 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
55 SEC
BURN
TIME
TIME (SEC)
PRES.
HP

5

2.6 Reentry Sensor Development

The POM reentry sensor is illustrated in the isometric drawing of Figure 27 and photographs in Figures 28 and 29. The reentry sensor is an inertial safe-arm switch which is locked in the safe position by a rotary solenoid. The device must be electrically unlocked during a specific time window of the terminal phase of the missile trajectory which represents a 2g ± 15% maximum deceleration. Once electrically unlocked, the reentry sensor is free to respond to a 5g + 30% reentry deceleration which will arm the switch. A telemetry switch will monitor the safe-arm condition of the reentry sensor. Should a reentry deceleration greater than 5g + 30% be sensed before the locking solenoid receives the electrical unlock signal, the inertial weight will be driven into the locking pins in the solenoid rotors preventing the solenoid from unlocking the system, therby dudding the reentry sensor in the safe position.

Once properly unlocked and 5g reentry deceleration level attained, the reentry sensor switch will translate from the safe to the arm position without the use of external energy. This is accomplished through a rotary switch operated by a 30 degree indexing mechanism attached to the inertial weight. The indexing mechanism holds the rotary switch in an open condition until the inertial weight is driven to the arm position. This action causes the indexing mechanism to close the normally open switch and retain the switch in this condition. The indexing rotary switch is non-latching for resettability. Should deceleration fall below the 5g level, the reentry switch will reset to the safe position and will be automatically relocked in this position, assuming the electrical energy has been removed from the rotary solenoid.



REENTRY SENSOR
PNEUMATIC CONTROL DEVICE

FIGURE 27

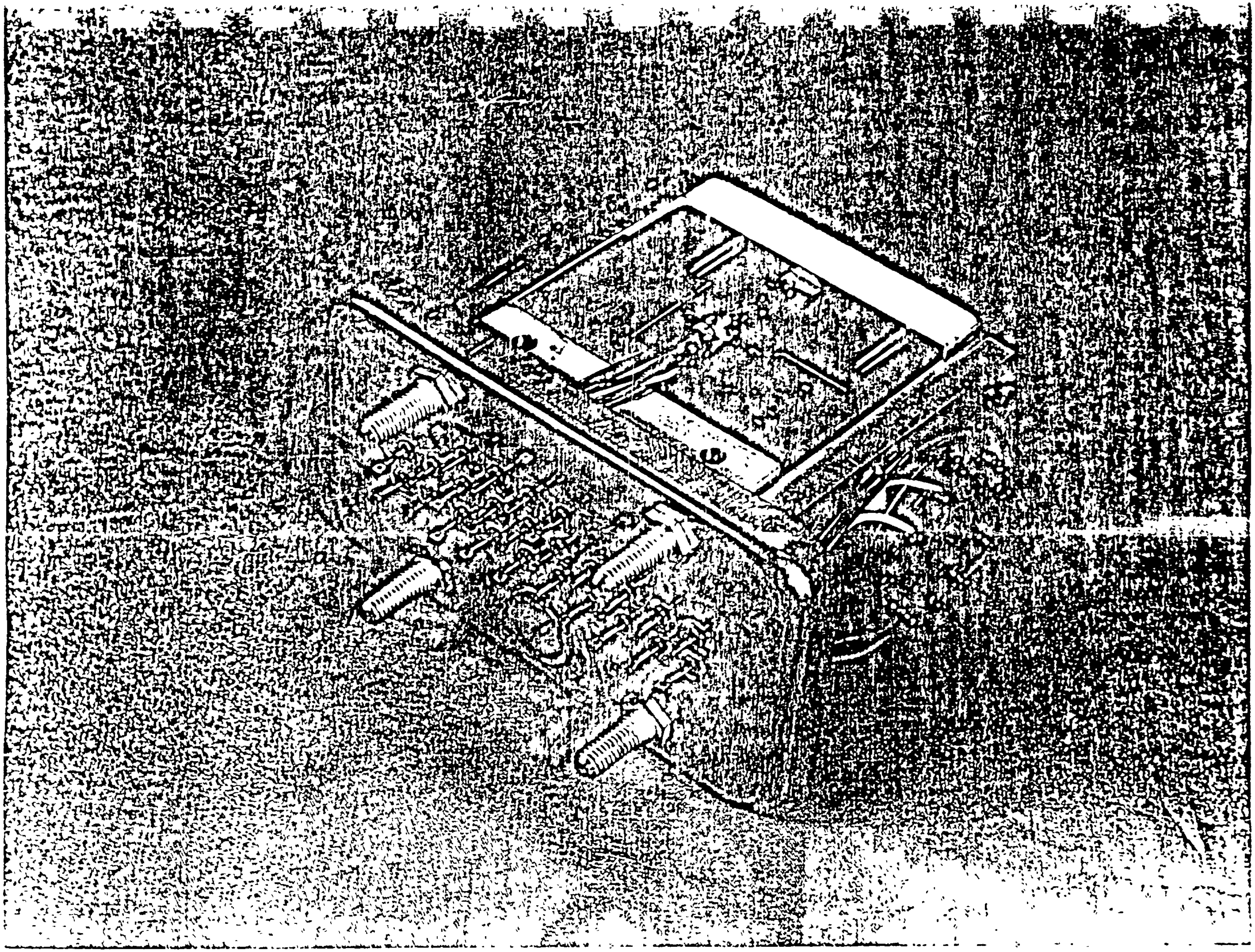


FIGURE 28 REENTRY SENSOR

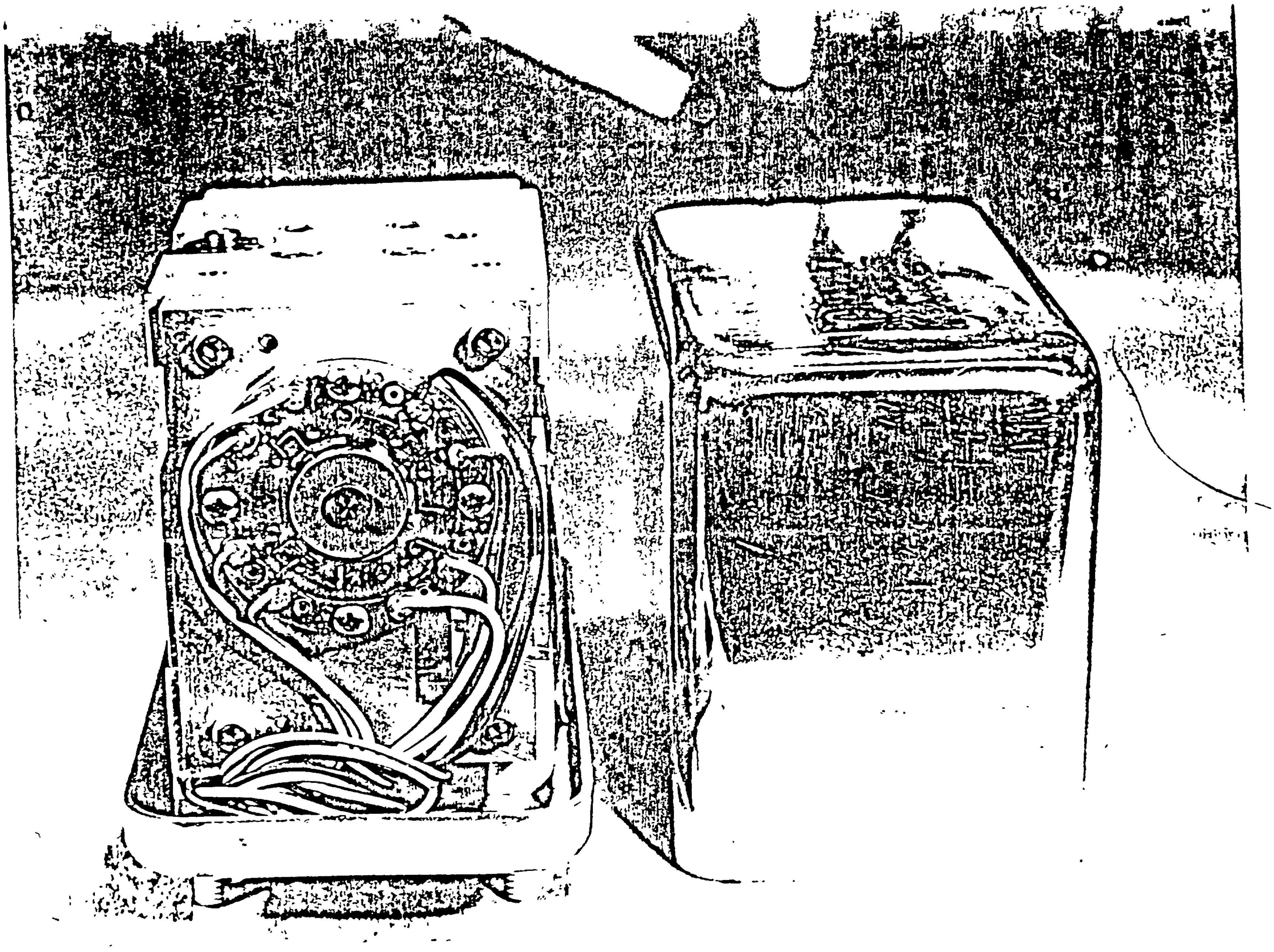


FIGURE 29 REENTRY SENSOR

The POM design of the reentry sensor shown in Figure 30 consists of a balanced double-lock rotary solenoid, an inertial weight with constant force bias spring, ball bushings, an indexing mechanism, and a rotary switch. An analysis was performed of the reentry sensor during the preliminary design to predict as accurately as possible the performance during superimposed dynamic loads of axial deceleration, lateral g-loading and vibration. This analysis indicated damping may be required for the spring mass system to respond as intended. A breadboard model of the reentry sensor design was fabricated and tested to empirically answer this question. Damping was provided in the breadboard model by a verge escapement. The reentry sensor model was subjected to vibration (random and sinusoidal) testing combined with sustained axial acceleration of the g-sensing weight assembly. The breadboard was evaluated with 4g, 5.5g, and 7g biased spring mass system. Two important conclusions from this evaluation are: the damping originally anticipated for the spring mass function was not required, and the sliding switch design was not adequate for switch chatter during random vibration. Breadboard testing with the escapement disconnected determined the maximum excursion of the g-sensing weight assembly (less than 1/64 of an inch for 5.5g bias spring) during reentry vibration conditions with a superimposed constant acceleration force of 2g's would not cause the blocking solenoid to interlock with the weight and dud the device during solenoid function. The preliminary design for the reentry sensor was changed to reflect the information gained by the breadboard evaluation. The escapement was eliminated and the switch design was altered to incorporate the rotary switch design from the Lance Arm-Safe Device shown in Figure 30, which proved to be an excellent switch for switch chatter.

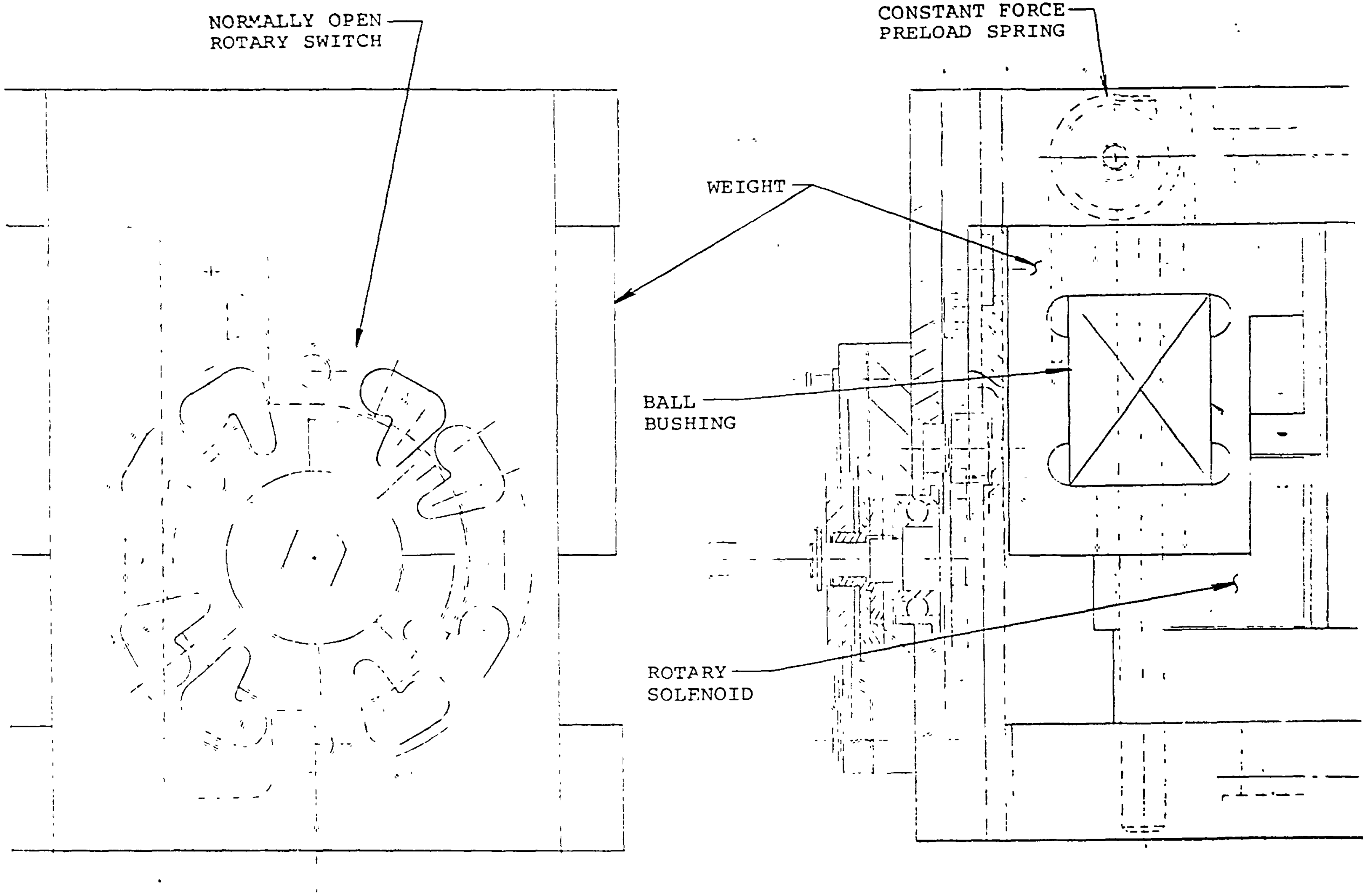


FIGURE 30 REENTRY SENSOR DESIGN

A preliminary operating model was fabricated and tested which proved to be operational and met the design requirements. This unit will not require redesign for the next phase except for the possible modification of the transportation lock which interfaces with the exo or propulsion environmental safe-arm device.

2.7 Conclusion

The final PCD valve control mechanism and hot gas generator preliminary operating models were successfully demonstrated at Avco and REI. All problems that occurred during development were solved and hardware modifications/redesigns were completed during the Phase 1 program. The feasibility of the PCD design was verified through POM tests.

The hot gas generator design will require tailoring to meet the required gas horsepower profile. This effort will be accomplished in the second phase of this program based on the turbo/alternator gas generator compatibility tests which established the actual gas horsepower requirements.

APPENDIX A

PCD - S/R ANALYSIS

Pershing II Adaption Kit

Pneumatic Control Device

System Safety/Reliability Analyses

Revision 1

1

1.0 System Description.

The Pneumatic Control Device (PCD), as shown in the electrical schematic of Figure 1-1 and the mechanical schematic of Figure 1-2 is a dual channel, fail-safe, electromechanical device whose function is to provide warm gas to the turbo-alternator in the Warhead Power Converter Assembly (WPCA) upon receipt of the correct type and sequence of Safing/Arming Control Assembly (SACA) and environmental inputs.

The SACA is required to provide each channel of the PCD with:

- A coded signal consisting of a four line, 12 bit code with synchronized clock to drive the enable mechanism through a rotation of 240° and unlock the control valve driver.
- A good separation signal to power the control valve driver to rotate the valve to the arm position after the normally open enable mechanism switch has been actuated.
- A firing signal to initiate the warm gas generator.

These inputs to the PCD are processed by, or through, three (3) major PCD components to provide for a fail safe-device. The coded signal is processed by the control valve enable mechanism to provide both mechanical and electrical unblocking. An error or failure of this component results in a continued lock on the valve driver and an open electrical circuit to the control valve driver. The good separation signal, which provides power to the control valve driver, is blocked by a normally open switch on the enable mechanism. The gas generator firing

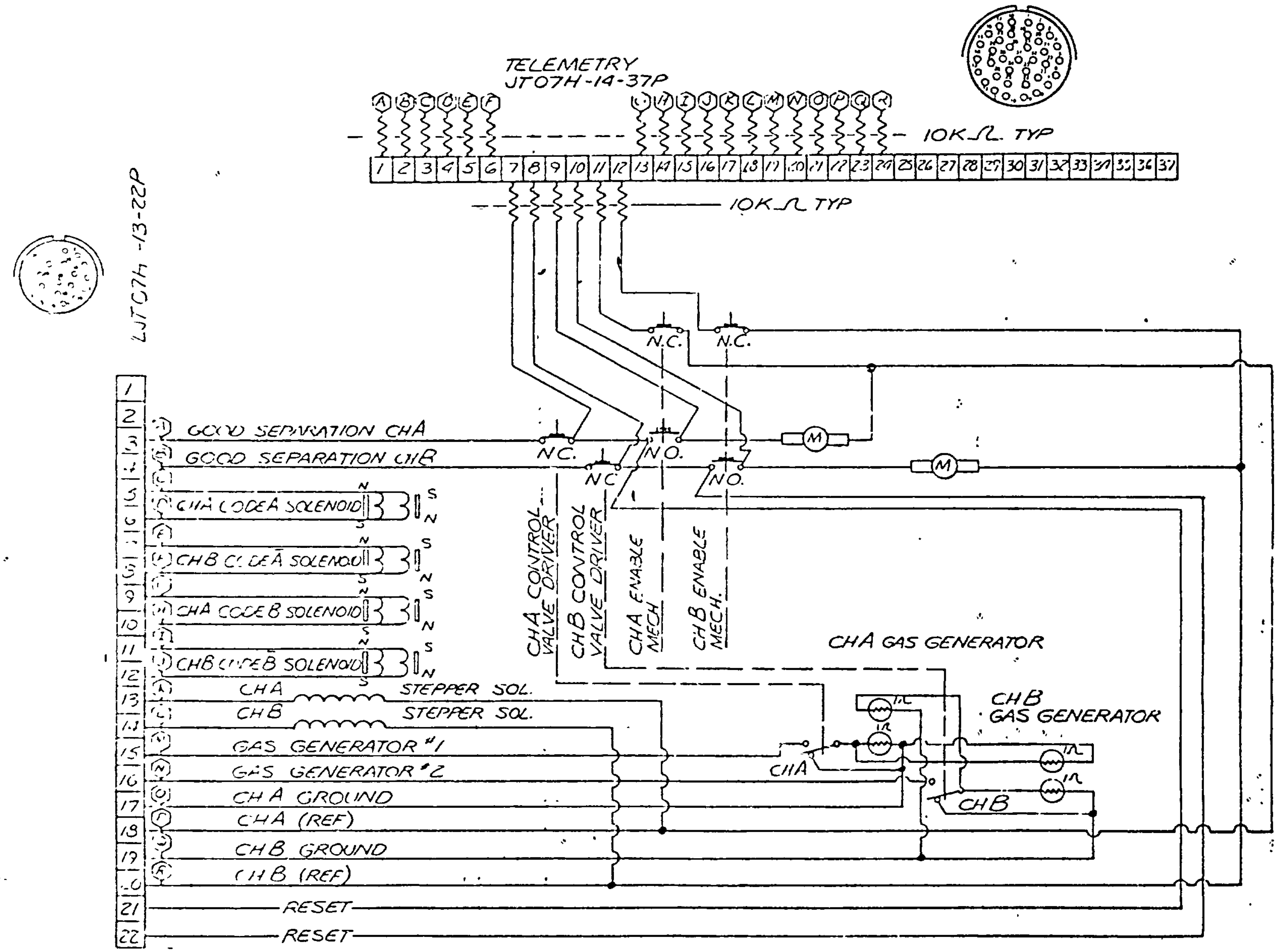
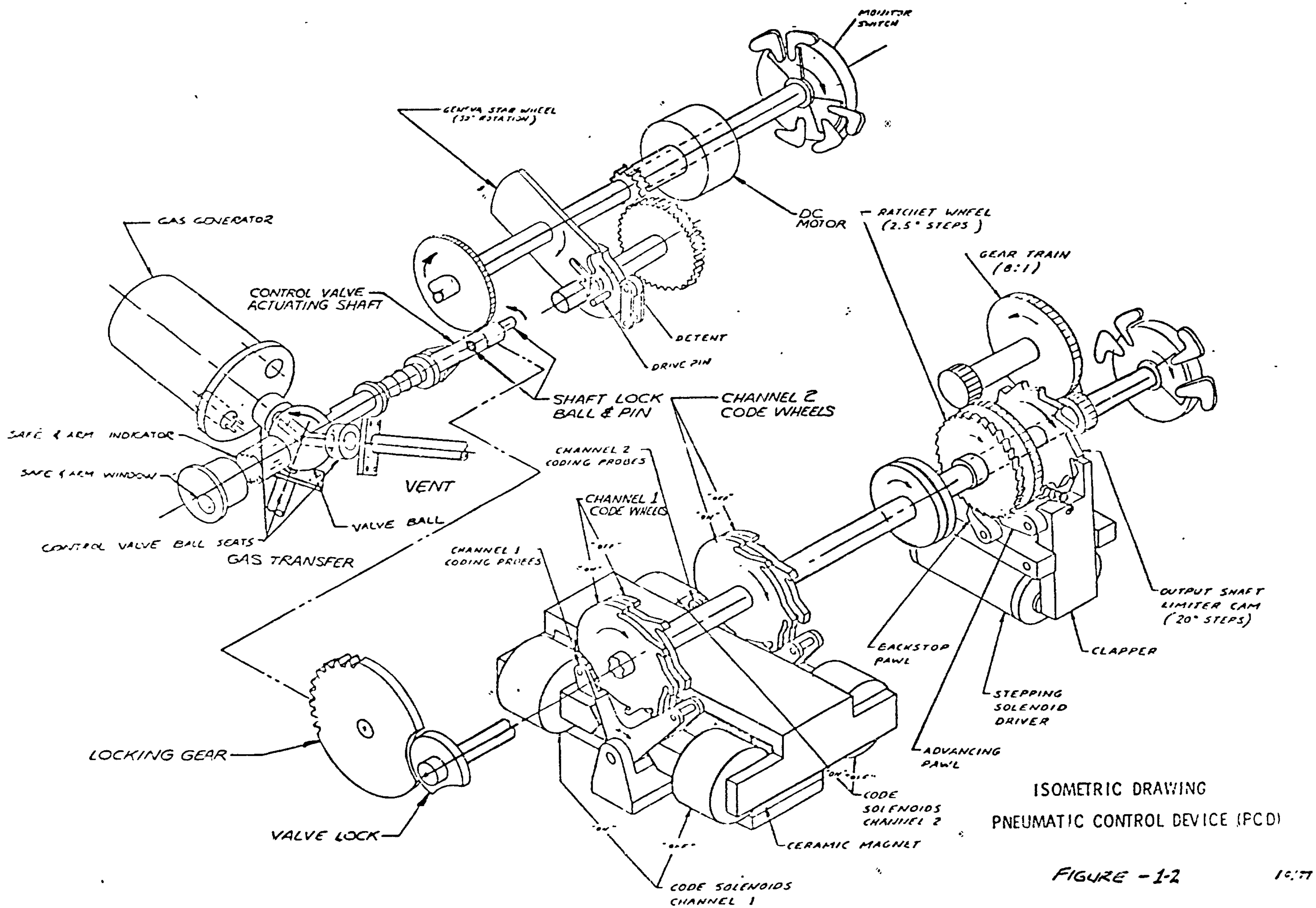


FIGURE 1-1 PCD ELECTRICAL SCHEMATIC

10/77



ISOMETRIC DRAWING

PNEUMATIC CONTROL DEVICE (PCD)

FIGURE -1-2

10:77

signal is blocked by an open circuit until the control valve driver rotates the valve into the "ARM" position and then closes the firing circuit switch. All of these conditions provide for a fail-safe operation in that:

- Failure of the enable mechanism leaves a mechanical and electrical block on the valve in the safe position.

- Failure in the valve driver mechanism leaves the valve in the safe position.

- An inadvertent firing of the gas generator with the valve in the safe position vents the gases through the safety port and away from the WPCA transfer line.

- An early firing signal to the gas generator is electrically blocked by the open circuit on the valve driver.

The PCD has two independent channels, completely isolated within the housing except for the common input and telemetry connectors. Even so, the input lines to the channels are independent within the connector. A failure of a component in one channel will not in any way affect the operation of the second channel.

2.0 PCD System Safety Analysis.

2.1 Introduction.

A Failure Mode and Hazardous Effects Analysis (FMHEA) and Fault Tree Analysis (FTA) have been completed and updated on the Pneumatic Control Device configuration designed as a part of Phase I of the Pershing II Adaption Kit Program.

The analyses have been accomplished in accordance with CDRL A013 (Safety Analyses and Hazard Evaluation Reports) and in conformanee with DI-H-1326A, Safety Analyses and Hazard Evaluation Reports; Section 2b, Failure Mode and Hazardous Effects Analysis, and Section 2c, Fault Tree Analysis.

This analysis (Revision 1) reflects the following changes and additions since the original analysis:

- Shaft lock & ball added to design.
- Additional detailed part information.
- Fault Tree Analysis broadened to include possibilities of a premature gas generator initiation.
- Omission of Reentry Sensor analyses due to devices relocation to the SACA subassembly.

2.2 Purpose.

The purpose of the safety analysis was to identify potential failure modes within the PCD that could cause or contribute to a personnel or equipment hazard. As defined by the Statement of Work "premature transfer of the control valve" is considered to be the major undesired event.

The FMHEA contains the safety failure modes of each major subcomponent. Thess modes have been logically combined in the FTA to indicate what single or multiple failures, if occurring, that could cause this undesired event.

2.3 Conclusion.

There are no single failure modes in the PCD that could cause the control valve to transfer prematurely.

It requires a minimum of five co-existing fault events before "premature transfer of the control valve" (warm gas generator output) can occur. These fault events are discussed in Section 2.5.

2.4 Recommendations.

1) Isolate 28VDC torque motor wiring from all sources of PCD 28VDC inputs such as stepper solenoid clock, enable mechanism code, and gas generator initiate signals.

2) Isolate both the "good separation" and "gas generator initiate" circuits from all adjacent current carrying pins within the PCD input electrical connector.

With the recommendations incorporated, safety of the PCD can be optimized without affecting inherent reliability.

2.5 Discussion of Safety Analyses.

Individual safety related failure modes were derived for each of the PCD subcomponents; control valve, control valve driver, warm gas generator, enable mechanism, and internal interconnections including telemetry circuitry. Failure modes such as premature PCD input signals from the SACA have been noted but not analyzed. These inputs will be studied during a system integrated fault tree analysis later in the program.

Failure modes and their effects are included as part of the FMHEA. Factors influencing or preventing their occurrence are also discussed.

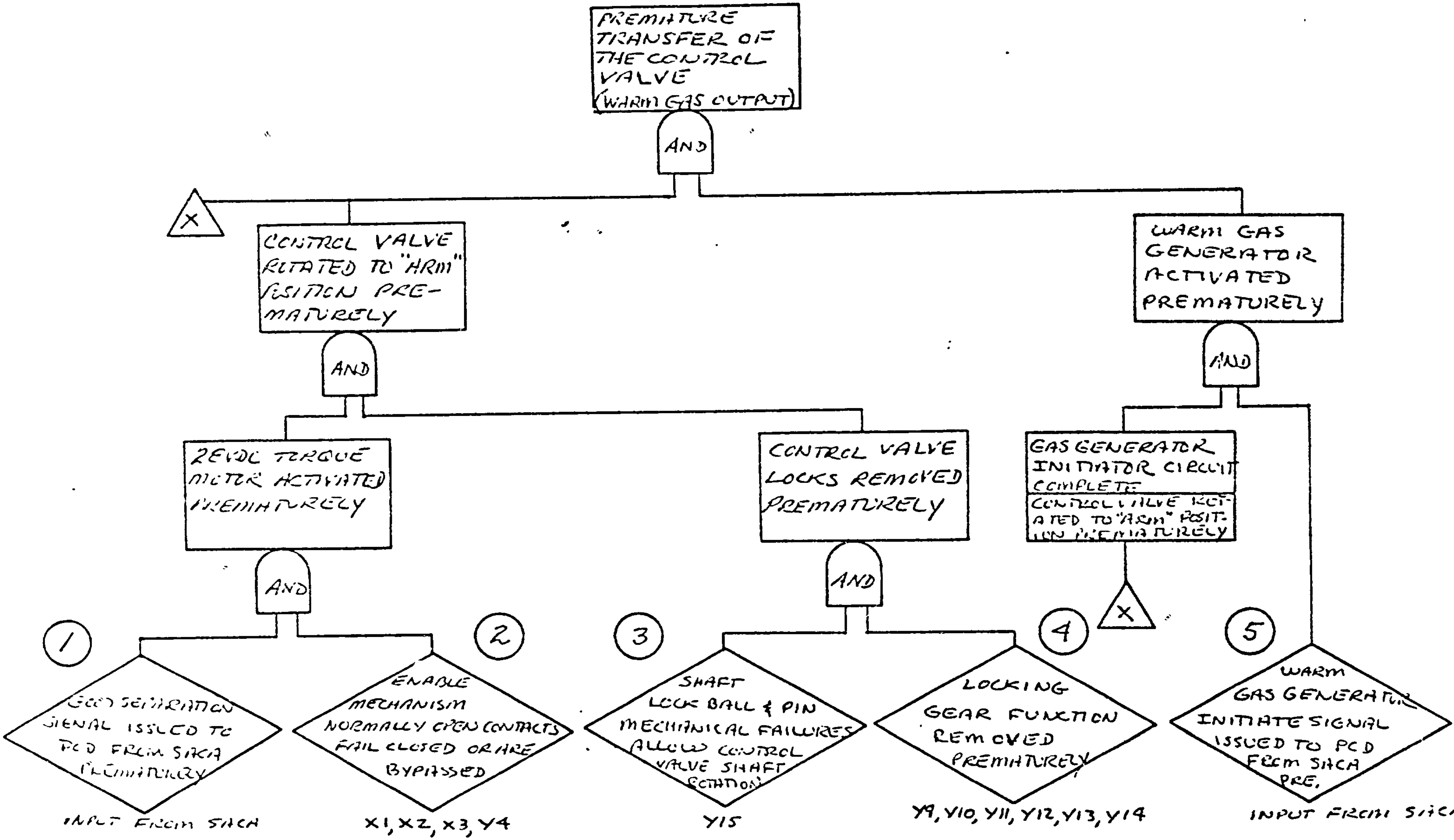
The failure modes from the FMHEA are integrated into the FTA which logically combines all potential safety related failures to determine what multiple failures could occur that would result in the undesired event "premature transfer of the control valve" (warm gas generator output).

Results of the FTA (Figure 2-2) indicate that for a premature PCD output (warm gas output to WFCA) to occur would require the coexistence of five (5) simultaneous fault events.

Failure modes hypothesized for this occurrence are shown in the simplified fault tree (Figure 2-1) and are:

1. Good Separation signal issued to the PCD from the SACA prematurely.
2. Enable Mechanism normally open contacts fail closed or are by-passed (FTA codes - X1, X2, X3, Y4).
3. Shaft Lock Ball and pin mechanical failures allow the control valve shaft free to rotate (FTA Code - Y1).
4. Locking gear function removed prematurely (FTA Codes - Y9, Y10, Y11, Y12, Y13, Y14).
5. Warm gas generator "initiate" signal issued to PCD from SACA prematurely.

Fault events 1 and 5, premature SACA electrical inputs to the PCD, are beyond the control of the PCD subassembly. Protection against these events are dependent on the SACA.



NOTE: REFERENCE FTA FIGURE-

SIMPLIFIED FAULT TREE — (REV. 1 10/77)

FIGURE 3-1 PNEUMATIC CONTROL DEVICE

Fault events 2 3 and 4 are PCD dependent. The failure mechanisms are hypothesized due to the early status of design. Some faults may not be real due to design layout and controls not observed as yet. This study however, does provide designers the identification of potentially critical areas that can be eliminated or controlled by isolating critical wires and quality control procedures to monitor mechanical part integrity and proper installation.

This analysis demonstrates that the PCD is a very safe device possessing more than adequate protection and controls against a premature output.

The analyses represent a qualitative assessment of only one channel of two contained within the PCD. Any failures discussed of the one channel are appropriate for the other. The overall quantitative safety of the PCD therefore would be reduced by a factor of 2.

2.6 Connector Analysis.

Investigation indicates that consideration should be given to optimizing safety of the PCD input electrical connector by reassigning certain critical circuit inputs.

As with all male connectors and pin layouts, short circuits are possible between adjacent pins due to bent pins or conductive contaminants. The present pin assignments of the PCD input electrical connector has some undesirable potential short circuit possibilities.

The "good separation" circuits (pins 3 and 4) and "gas generator initiate" circuits (pins 15 and 16) are considered to be safety critical. The former circuit drives the control valve to the "ARM" position, and the latter initiates the warm gas generator initiators.

Although each circuit is "open" internally by normally open switch contacts until certain operating conditions have occurred, the possibility of shorts between the input of these circuits and live voltages from adjacent sources enable mechanism code (Pins 5 through 12), and stepper solenoid clock (pins 13 and 14) is undesirable due to the possibility of inadvertent voltage shorting to these critical circuits. Coupled with the possibility of additional failures within the PCD, inadvertent DC torque motor or gas generator activation could occur.

Both the "good separation" and "gas generator initiate" circuits should be isolated (non-adjacent) from all other current carrying pins within the input electrical connector. This can be accomplished by strategically reassigning circut pin designations. Isolation at the backside (internal) of the connector is being provided via ribbon type wiring layouts.

Optimization of the electrical connector pin layout would further enhance PCD safety without affecting reliability.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD) P/N 2379-300

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Warm gas generator.	Provide warm gas to drive WPCA turboalternator at predetermined time during missile flight.	Propellant/ Initiators.	1) Autoignition (X7, X8). 2) Impact shock (Y16, Y18). 3) Temperature in excess of TBDL °F. (Y17, Y19).	Affected PCD channel inoperative after approximately 55 seconds of outgassing.	II (Marginal)	1) Initiators: a) 1 amp - 1 watt, 5 minute no fire devices. b) Temperature in excess of TBDL °C for TBDL would cause initiation. c) Impact shock in excess of TBDL would cause initiation. d) Initiators shunted for handling as components and when installed in PCD. 2) Propellant: a) Temperature in excess of 375° for 1 Hour would cause initiation. b) Impact shock in excess of TBDL would cause initiation. 3) General: a) Inadvertent initiation-gas vented through PCD safety port. b) Visual indicator on control valve indicates "SAFE" or "ARM" position and relative initiator shunt status. 4) Ignition charge - [illegible] Sensitivities - TBDL

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SHEET 2 OF 9

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Warm gas generator inter-connections.	Provide electrical connections for initiation circuits and shunts.	Wiring.	Initiator normally open contact wiring short circuits (Y20).	Initiate circuit complete.	I (Negligible)	Initiator shunts preclude in-advertent gas generator initiation.
			Initiator shunt wire fails open (X11).	Initiator shunt removed. Initiator susceptable to stray voltage.	I	Initiator firing circuit open normally open contacts.
			Safe side of initiator normally open contacts wire shorts to good separation circuit wire. (Y22).	Initiator would be susceptable to good separation signal voltage inadvertently (T_{CO}+ 365s).	I	Initiator shunts preclude in-advertent gas generator initiation.
			Initiate (+) circuit wire shorts to good separation circuit wire (Y 23)	Initiator circuit would be susceptable to good separation signal voltage inadvertently (T_{CO}+ 365s)	I	Initiator firing circuit open by normally open contacts and initiator shunts preclude in-advertent gas generator initiation.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Warm gas generator interconnections (cont'd).		Wiring	Safe side of initiator normally open contacts wire shorts to Enable Mechanism Code wire (Y24).	Initiator would be susceptable to Enable Mechanism signal voltage (T_{CO}+ 364s).	I	Initiator shunts preclude inadvertent gas generator initiation.
			Initiator (+) circuit wire shorts to Enable Mechanism circuit wire (Y25).	Initiator circuit would be susceptable to Enable Mechanism signal voltage inadvertently (T_{CO}+ 364s)	I	Initiator firing circuit open by normally open contacts and initiator shunts preclude inadvertent gas generator initiation.
			Safe side of initiator normally open contacts wire shorts to Stepper Solenoid clock wire (Y26)	Initiator would be susceptable to Stepper Solenoid signal voltage inadvertently (T_{CO}+ 364s).	I	Initiator shunts preclude inadvertent gas generator initiation.
			Initiate (+) circuit wire shorts to Stepper Solenoid clock wire (Y27)	Initiator circuit would be susceptable to Stepper Solenoid clock voltage inadvertently (T_{CO} + 364s).	I	Initiator firing circuit open by normally open contacts and initiator shunts preclude inadvertent gas generator initiation.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Warm gas generator interconnections (Cont'd).		PCD Input Electrical Connector.	Initiate (+) circuit connector pin shorts to good separation circuit pin. (X12).	Initiator circuit would be susceptable to good separation signal voltage inadvertently (T_{CO} + 365s).	I	Initiator firing circuit open by normally open contacts and initiator shunts preclude inadvertent gas generator initiation.
			Initiate (+) circuit connector pin shorts to Enable Mechanism Code pin (X13).	Initiator circuit would be susceptable to Enable Mechanism signal voltage inadvertently (T_{CO}+ 364s).	I	"
			Initiate (+) circuit connector pin shorts to Stepper Solenoid clock connector pin (X14).	Initiator circuit would be susceptable to Stepper Solenoid clock voltage inadvertently (T_{CO} + 364s)..	I	"
		Initiator circuit normally open contacts.	Contacts fail shorted (X9).	Initiator circuit complete.	I	Initiator shunts preclude inadvertent gas generator initiation.
		Initiator circuit normally closed contacts.	Contacts fail open (X10).	Initiator shunt removed. Initiator susceptable to stray voltages.	I	Initiator firing circuit open by normally open contacts.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SHEET 5 OF 9

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Control Valve.	Provides passageway for warm gas generator output to either the transfer line (WPCA Turbo-alternator) or safety port.	Control valve ball/drive shaft.	Control valve ball or shaft fractured above locking devices (Y 1).	Warm gas from generator will not transfer to WPCA turboalternator. Control valve unable to rotate to "ARM" position.	I	1) Warm gas vented through the safety port if generator activated inadvertently. 2) Control valve restricte from free rotation by frictional forces of wedge shaped encapsulat of ball. (Minimum force required to rotate > 10 inch ounces to overcome inherent friction). (≥1 3) Excessive shock or vibration required to rotate ball. (Y2).
		Control valve shaft locking gear.	Control valve locking gear not installed (Y9).	Control valve positive lock not utilized as designed.	I	Loss of locking gear backed up by shaft lock ball & pin.
		Shaft lock ball & pin.	Mechanical failures allow shaft free rotation (Y15).	Control valve positive lock not utilized as designed.	I	Control valve prevented from inadvertent rotati by enable mechanism.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Control Valve (cont'd).		Control valve shaft locking gear (cont'd).	Control valve locking gear fracture (Y10).	"	I	1) Control valve restricted from free rotation by shaft lock ball & pin. 2) Control valve DC torque motor (drive) circuit normally open.
			Major displacement of control valve locking gear mating to enable mechanism valve lock (Y12).	"	I	Housing space limitations do not allow sufficient tolerance to permit major displacement and subsequent unmating.
			Locking gear misaligned with control valve shaft pinion. (Y11).	"	I	Control valve prevented from inadvertent rotation by enable mechanism and shaft lock ball & pin.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Control Valve Driver.	Provides torque required to rotate control valve from "SAFE" to "ARM" position upon receipt of "good separation" signal from SACA.	DC torque motor.	Torque motor input lead shorted to initiator input lead (Y3).	Torque motor susceptable to premature initiate voltage.	I	Control valve prevented from rotation by enable mechanism and shaft lock ball & pin.
			Torque motor input lead shorted to good separation input lead (Y4).	Torque motor susceptable to premature good separation voltage.	I	"
			Torque motor input lead shorted to Enable Mechanism code input lead (Y5).	Torque motor susceptable to premature enable mechanism voltage.	I	"
			Torque motor input lead shorted to stepper solenoid clock input lead (Y6).	Torque motor susceptable to premature stepper solenoid clock voltage.	I	"
			Torque motor telemetry lead shorted to either of 4 input voltage leads (Y7).	Torque motor susceptable to premature voltage inputs to PCD.	I	"

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS - REV. 1

SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Control Valve Enable Mechanism	Provide physical lock of the control valve drive shaft until proper coded signals are received from the SACA during missile flight.	Enable Mechanism 've lock.	Valve lock fractured.(Y13).	Control valve positive lock not utilized as designed.	I	1) Control valve restricted from rotation by shaft lock ball & pin. 2) Control valve DC torque motor (drive) circuit normally open.
			Valve lock not installed.(Y14).	"	I	
		Enable Mechanism wheel assembly.	Mechanical failures e.g.,wheels not secured to shaft. (Y8).	"	I	All four code wheels would hav to be free of shaft before positive lock would be ineffec ive.
		Enable Mechanism normally open contacts in 'good separation"circuit	Contacts fail closed,contamination. (X1).	DC torque motor circuit complete.	I	Control valve prevented from inadvertent rotation by enable mechanism and shaft lock ball & pin.
		Wiring.	Control valve normally closed contact wire and Enable Mechanism normally open contact telemetry wire short. (X3).	"	I	"
			Enable Mechanism normally open contacts wires fail shorted.(X2).	"	I	"

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS-REV. 1

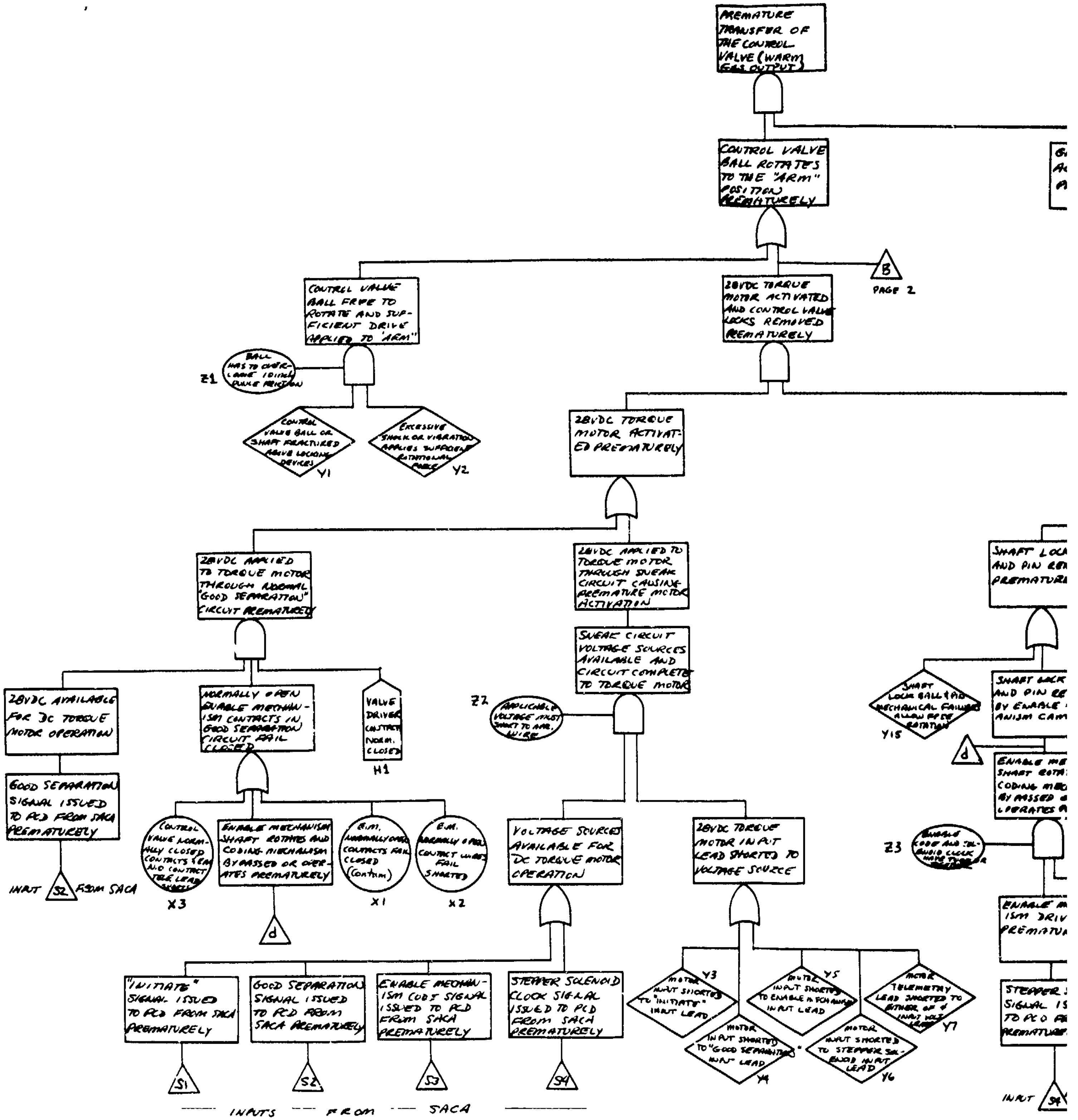
SUBSYSTEM - Pneumatic Control Device (PCD)

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS

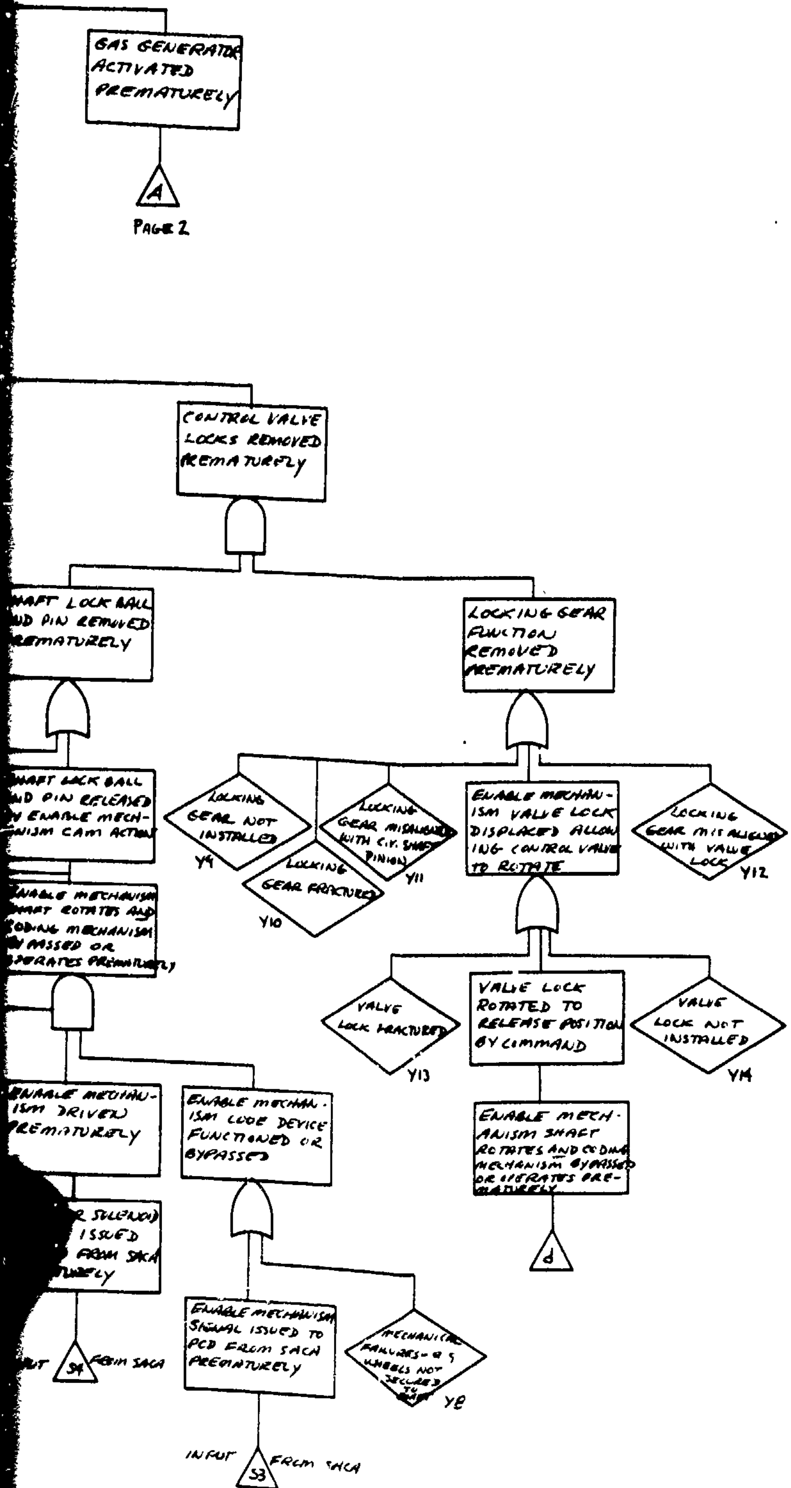
NOTE:

HAZARD CLASSIFICATION -MIL-STD-882:
Conditions such that personnel error, environment, design characteristics, procedural deficiencies, or subsystem or component failure or malfunction:

(a) Category I - Negligible ....will not result in personnel injury or system damage.
(b) Category II- Marginal.......can becounteracted or controlled without injury to personnel or major system damage.
(c) Category III-Critical.......will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival.
(d) Category IV- Catastrophic...will cause death or severe injury to personnel or system loss.



PREMATURE TRANSFER OF THE CONTROL VALVE (WARM GAS OUTPUT)
CONTROL VALVE BALL ROTATES TO THE "ARM" POSITION PREMATURELY
PAGE 2
CONTROL VALVE BALL FREE TO ROTATE AND SUFFICIENT DRIVE APPLIED TO "ARM"
28VDC TORQUE MOTOR ACTIVATED AND CONTROL VALVE LOCKS REMOVED PREMATURELY
Z1
Y1
Y2
28VDC TORQUE MOTOR ACTIVATED PREMATURELY
28VDC APPLIED TO TORQUE MOTOR THROUGH NORMAL "GOOD SEPARATION" CIRCUIT PREMATURELY
28VDC APPLIED TO TORQUE MOTOR THROUGH SNEAK CIRCUIT CAUSING PREMATURE MOTOR ACTIVATION
SNEAK CIRCUIT VOLTAGE SOURCES AVAILABLE AND CIRCUIT COMPLETE TO TORQUE MOTOR
Z2
28VDC AVAILABLE FOR DC TORQUE MOTOR OPERATION
GOOD SEPARATION SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
INPUT
FROM SACA
VALVE DRIVER CONTACTS NORM. CLOSED
H1
ENABLE MECHANISM SHAFT ROTATES AND CODING MECHANISM BYPASSED OR OPERATES PREMATURELY
X3
X1
X2
VOLTAGE SOURCES AVAILABLE FOR DC TORQUE MOTOR OPERATION
28VDC TORQUE MOTOR INPUT LEAD SHORTED TO VOLTAGE SOURCE
Y3
Y4
Y5
Y6
Y7
"INITIATE" SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
GOOD SEPARATION SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
ENABLE MECHANISM CODE SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
STEPPER SOLENOID CLOCK SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
S1
S2
S3
S4
INPUTS FROM SACA
Y15
Z3

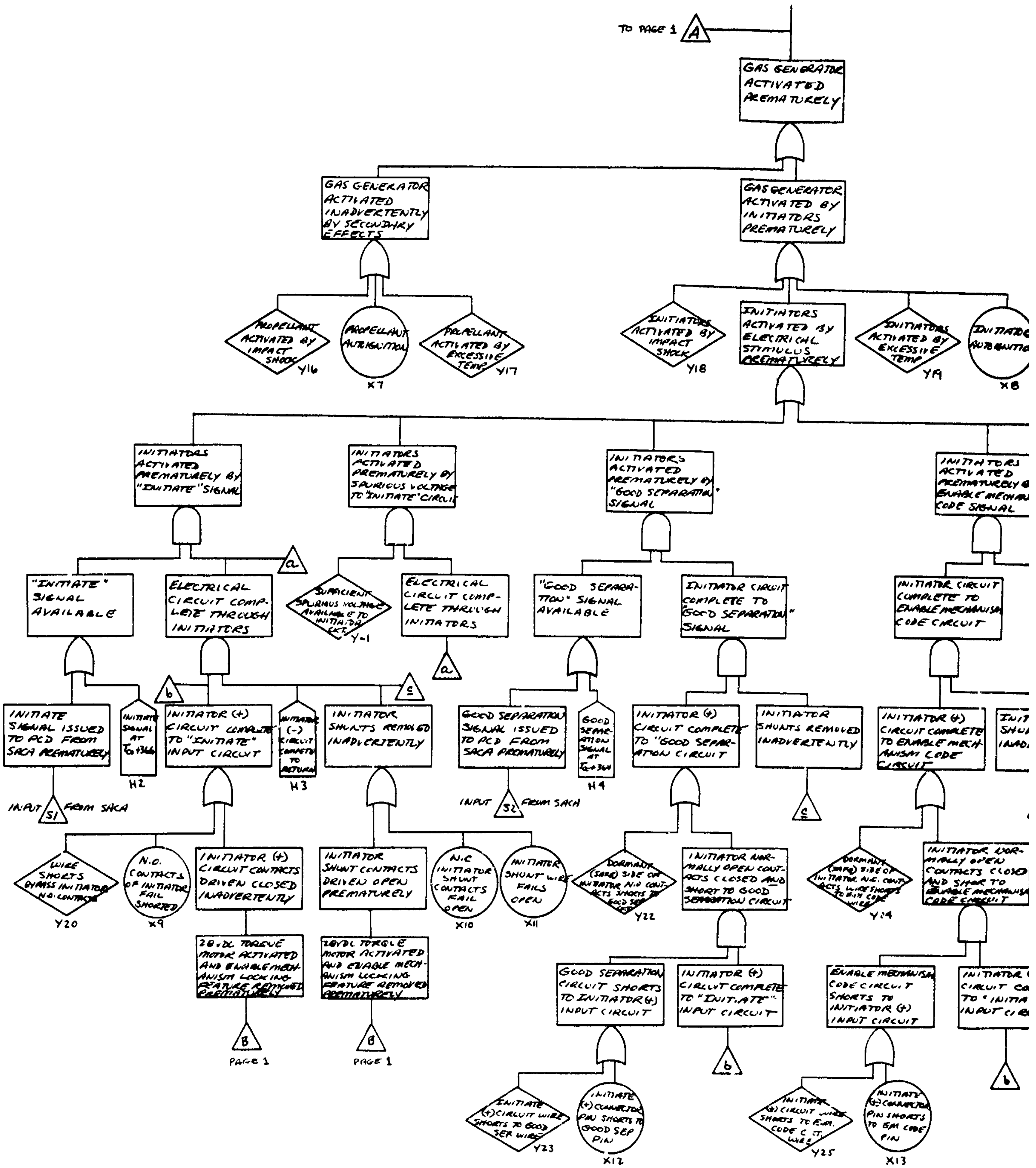


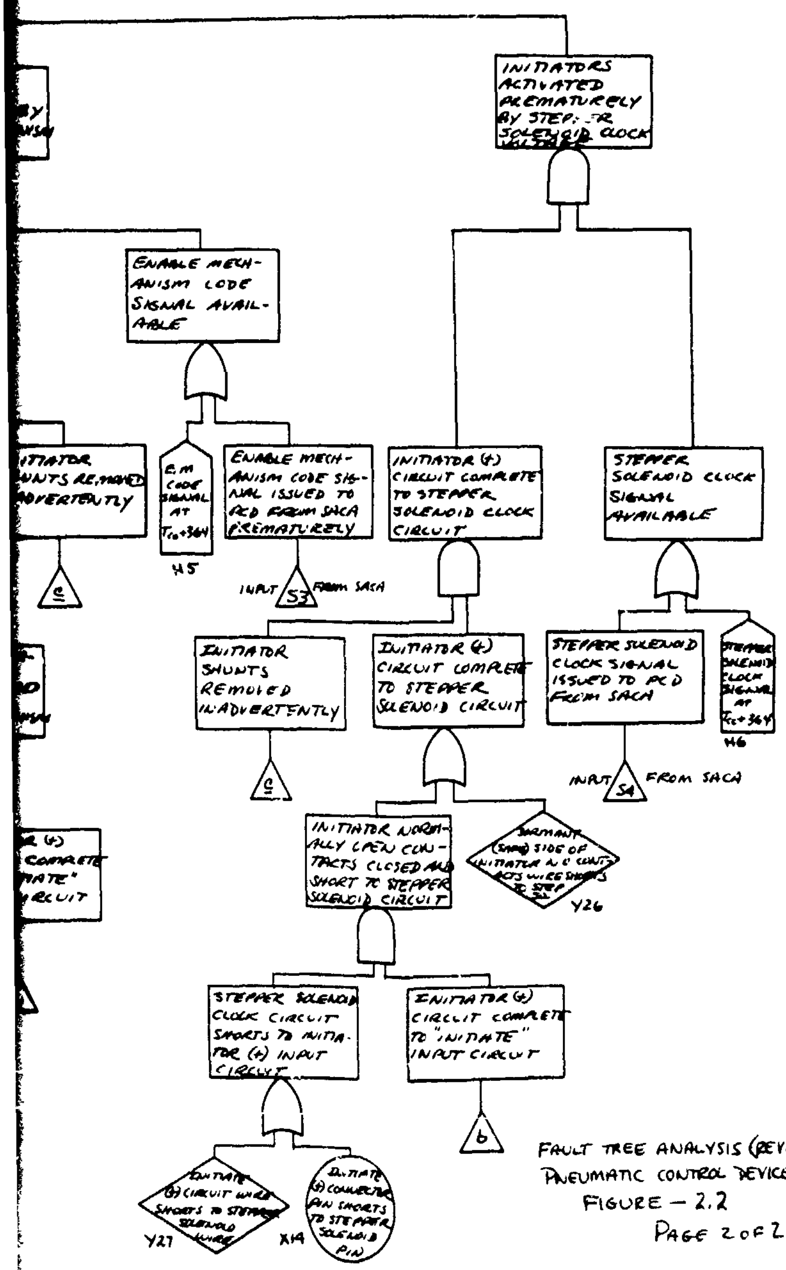
FAULT TREE ANALYSIS (REV 9/77)

PNEUMATIC CONTROL DEVICE

FIGURE – 2.2

PAGE 1 OF 2


TO PAGE 1
A
GAS GENERATOR ACTIVATED PREMATURELY
GAS GENERATOR ACTIVATED INADVERTENTLY BY SECONDARY EFFECTS
GAS GENERATOR ACTIVATED BY INITIATORS PREMATURELY
PROPELLANT ACTIVATED BY IMPACT SHOCK
Y16
PROPELLANT AUTOIGNITION
X7
PROPELLANT ACTIVATED BY EXCESSIVE TEMP
Y17
INITIATORS ACTIVATED BY IMPACT SHOCK
Y18
INITIATORS ACTIVATED BY ELECTRICAL STIMULUS PREMATURELY
INITIATORS ACTIVATED BY EXCESSIVE TEMP
Y19
X8
INITIATORS ACTIVATED PREMATURELY BY "INITIATE" SIGNAL
INITIATORS ACTIVATED PREMATURELY BY SPURIOUS VOLTAGE TO "INITIATE" CIRCUIT
INITIATORS ACTIVATED PREMATURELY BY "GOOD SEPARATION" SIGNAL
"INITIATE" SIGNAL AVAILABLE
ELECTRICAL CIRCUIT COMPLETE THROUGH INITIATORS
SUFFICIENT SPURIOUS VOLTAGE AVAILABLE TO INITIATION CKT.
Y-1
ELECTRICAL CIRCUIT COMPLETE THROUGH INITIATORS
"GOOD SEPARATION" SIGNAL AVAILABLE
INITIATOR CIRCUIT COMPLETE TO "GOOD SEPARATION" SIGNAL
INITIATOR CIRCUIT COMPLETE TO ENABLE MECHANISM CODE CIRCUIT
INITIATE SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
INITIATE SIGNAL AT T_0+366
H2
INITIATOR (+) CIRCUIT COMPLETE TO "INITIATE" INPUT CIRCUIT
INITIATOR (-) CIRCUIT COMPLETE TO RETURN
H3
INITIATOR SHUNTS REMOVED INADVERTENTLY
GOOD SEPARATION SIGNAL ISSUED TO PCD FROM SACA PREMATURELY
GOOD SEPARATION SIGNAL AT T_0+364
H4
INITIATOR (+) CIRCUIT COMPLETE TO "GOOD SEPARATION CIRCUIT
INITIATOR SHUNTS REMOVED INADVERTENTLY
INITIATOR (+) CIRCUIT COMPLETE TO ENABLE MECHANISM CODE CIRCUIT
INPUT S1 FROM SACA
INPUT S2 FROM SACA
WIRE SHORTS BYPASS INITIATOR N.O. CONTACTS
Y20
N.O. CONTACTS OF INITIATOR FAIL SHORTED
X9
INITIATOR (+) CIRCUIT CONTACTS DRIVEN CLOSED INADVERTENTLY
INITIATOR SHUNT CONTACTS DRIVEN OPEN PREMATURELY
N.C INITIATOR SHUNT CONTACTS FAIL OPEN
X10
INITIATOR SHUNT WIRE FAILS OPEN
X11
DORMANT (SAFE) SIDE OF INITIATOR N.O. CONTACTS SHORTS TO GOOD SEP
Y22
INITIATOR NORMALLY OPEN CONTACTS CLOSED AND SHORT TO GOOD SEPARATION CIRCUIT
DORMANT (SAFE) SIDE OF INITIATOR N.C. CONTACTS WIRE SHORTS TO EM CODE WIRE
Y24
INITIATOR NORMALLY OPEN CONTACTS CLOSED AND SHORT TO ENABLE MECHANISM CODE CIRCUIT
28 VDC TORQUE MOTOR ACTIVATED AND ENABLE MECHANISM LOCKING FEATURE REMOVED PREMATURELY
28VDC TORQUE MOTOR ACTIVATED AND ENABLE MECHANISM LOCKING FEATURE REMOVED PREMATURELY
PAGE 1
PAGE 1
GOOD SEPARATION CIRCUIT SHORTS TO INITIATOR (+) INPUT CIRCUIT
INITIATOR (+) CIRCUIT COMPLETE TO "INITIATE" INPUT CIRCUIT
ENABLE MECHANISM CODE CIRCUIT SHORTS TO INITIATOR (+) INPUT CIRCUIT
INITIATE (+) CIRCUIT WIRE SHORTS TO GOOD SEP WIRE
Y23
INITIATE (+) CONNECTOR PIN SHORTS TO GOOD SEP PIN
X12
INITIATE (+) CIRCUIT WIRE SHORTS TO E.M. CODE C.T. WIRE
Y25
INITIATE (+) CONNECTOR PIN SHORTS TO EM CODE PIN
X13

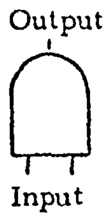


FAULT TREE ANALYSIS (REV.)
PNEUMATIC CONTROL DEVICE
FIGURE – 2.2
PAGE 2 OF 2

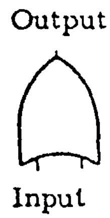
FAULT TREE ANALYSES

FAULT TREE SYMBOLOGY

Logic Operations:

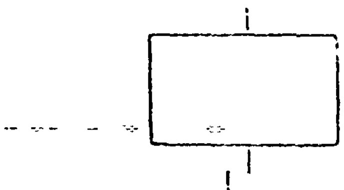


The AND GATE describes the logical operation whereby the coexistence of all input events are required to produce the output event.

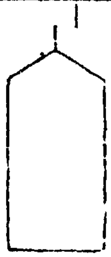


The OR GATE defines the situation whereby the output event will exist if any or all of the input events is present.

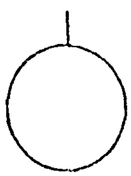
Event Presentation:



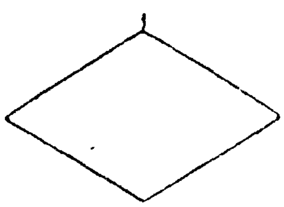
The RECTANGLE identifies an event, usually a malfunction, that results from the combination of fault events through the logic gates.



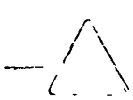
The HOUSE indicates an event that is normally expected to occur. For example, it may be used to represent the event, "Timing pulses present".



The CIRCLE describes a basic fault event that requires no further development. This category includes component failures whose frequency and mode of failure are derived through laboratory testing or historical data.



The DIAMOND describes a fault event that is considere basic in a given fault tree; however, the causes of the event have not been developed either because the event is a insufficient consequence or the necessary information is unavailable.



The TRIANGLES indicate transfer symbols. A line from the apex of the triangles denotes a transfer-in and a line from the side denotes a transfer-out.

FIGURE 2-3

3.0 PCD Reliability Analysis

3.1 Introduction

A failure modes, effects and criticality analysis (FMECA), and reliability block diagram have been completed and updated of the Pneumatic Control Device (PCD) configuration designed as a part of Phase I of the Pershing II Adaption Kit Program.

The analyses have been accomplished in accordance with CDRL A014 "Reliability Mathematical Model", and CDRL A015 "Reliability Failure Modes, Effects and Criticality Analyses Report", and in conformance with data items DI-R-1732 and DI-R-1734 with the same respective titles.

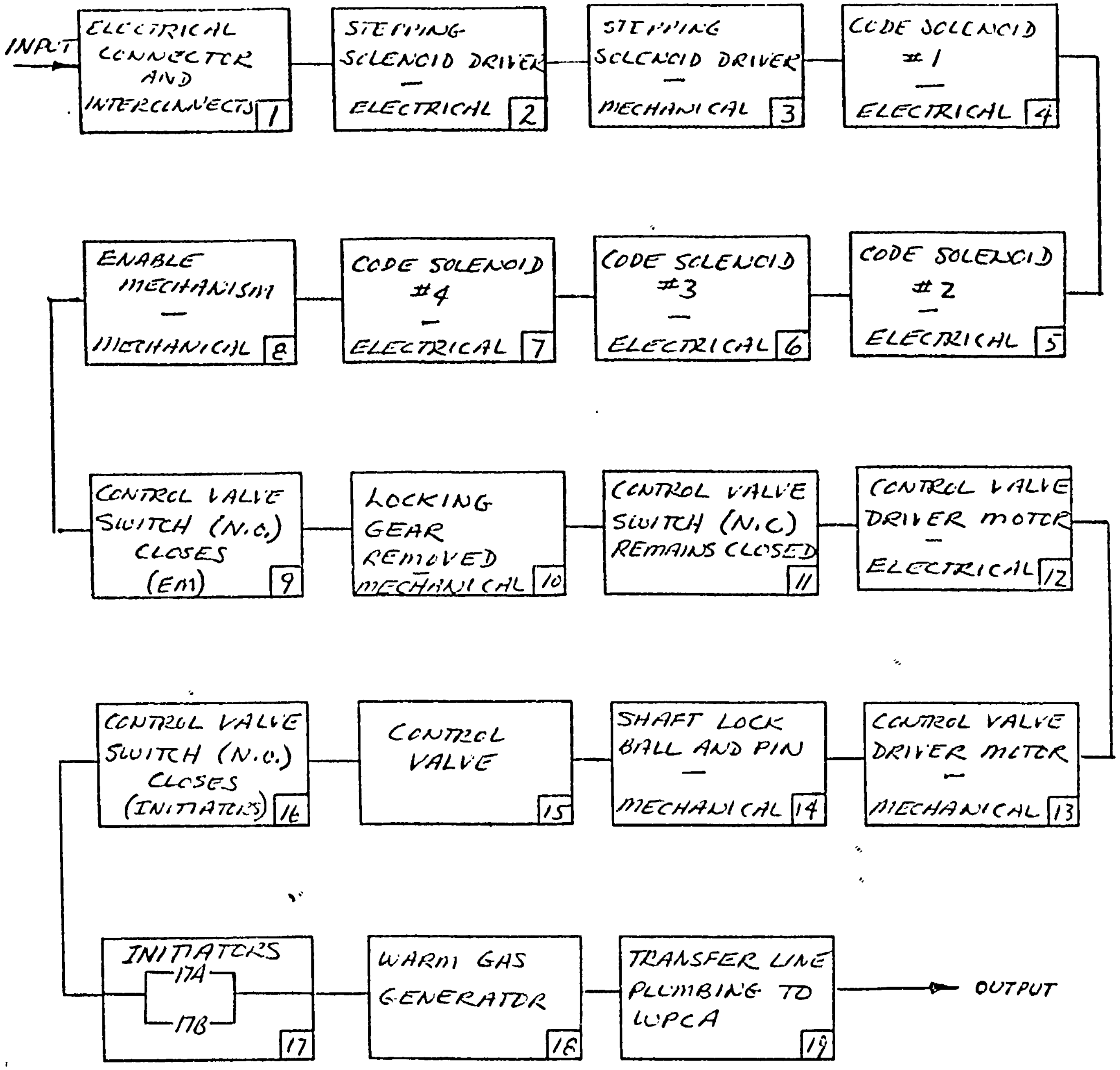
3.2 Failure Mode, Effects and Criticality Analysis (FMECA)

Attached is the FMECA for the PCD. It is presented in standard format and represents a preliminary examination of failure modes within the PCD. It should be noted that only one of the dual channels is discussed and failure of a piece part or assembly in one channel does not dud or affect the other channel.

The FMECA are being conducted on an iterative basis and will be updated periodically to reflect design changes, and to add additional detailed information as it becomes available.

3.3 Reliability Block Diagram

Figure 3-1 shows the serialized elements of one PCD channel. The use of dual channels, each of which is inherently reliable, assures a high probability of success for the PCD function. However, crossovers providing additional redundancy should be considered to improve or enhance PCD reliaility. The block diagram is provided for future use in assigning probabilities of success and subsequent PCD reliaility.



$$R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 R_9 R_{10} R_{11} R_{12} R_{13} R_{14} R_{15} R_{16} \left[R_{17}(2-R_{17})\right] R_{18} R_{19}$$

RELIABILITY BLOCK DIAGRAM & MATH MODEL (1 CHANNEL)

PNEUMATIC CONTROL DEVICE

FIGURE – 3-1

(Rev. 1 9/77)

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS

PROGRAM Pershing II Adaption Kit

SUBSYSTEM Pneumatic Control Device (PCD)

COMPONENT ______ PART NO. ______

SUBASSEMBLY ______ PART NO. ______

(One of the dual channels is treated)

SHEET 1 OF 8

PREPARED BY ______

SCHEMATIC 2379-300

These entries are made with the assumption that all required signals are present at the SACA/PCD interface connector, at the correct time and that all parts are installed.

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I. No or insufficient warm gas available at output of PCD Transfer Line to WPCA Turbo alternator (T/A).	Affected WPCA Turbo alternator channel not provided with sufficient high pressure warm gas to start and sustain the T/A at operating speed.	(See below)	The PCD is a dual channel device. In the event of a failure of one channel, successful operation of the other will provide high pressure warm gas to the applicable WPCA Turbo alternator.	Major
Ia. No or insufficient warm gas available at output of PCD Transfer Line to WPCA Turbo alternator due to Transfer Line failures.	"	1) Transfer Line fractured.	Cobalt-base super alloy-cast Haynes alloy 25 L-605 Tensile Strength 47,000 @ 1600°F	Major
		2) Transfer Line not secure at interfaces of PCD and/or WPCA.	Assembly/Quality Control function	
		3) Transfer Line crimped.	Tubing has to be heat treated to bend & shape	
		4) Obstruction in Transfer Line.	Assembly/Quality Control function	
Ib. No or insufficient warm gas available at output of PCD Transfer Line due to Warm Gas Generator failures.	"	1) Both Gas Generator Initiators fail to ignite.	SDI initiator-Qualified to MIL-I-23659 Rev. C	Major
		2) Ignition charge fails to deflagrate	Ignition charge is $BKNO_2$	

PART NO.
COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.b (Cont'd)		3) Gas Generator propellant fails to deflagrate.	Propellant is TAL-433 Rubber/ Ammonium Nitrate	
		4) Gas Generator propellant burns rapidly due to excessive surface area ignition.	Proper packaging/handling/ Quality Control should minimize fragmentization of ordnance material.	
Ic. No warm gas available at output of PCD Transfer Line due to Warm Gas Generator Initiators not receiving proper 28 volt firing signal.	Affected Warm Gas Generator not activated.	1) Initiator (+) circuit wiring or connector pin shorted or open.	Wire-28 guage-Teflon insulated. Connector MIL-C-38999.	Major
		2) Initiator (-) circuit wiring or connector pin open.	Wire-28 guage-Teflon insulated. Connector MIL-C-38999.	
		3) Initiator firing circuit normally, open contacts fail to close.	Dual gold plated contactors. One contactor per each side of engaging blade.	
Id. No or insufficient warm gas available at output of PCD Transfer Line due to failures associated with the Control Valve or its arming mechanisms.	Affected PCD Channel does not transfer warm gas generator output to applicable WPCA Turbo alternator.	(See below)	(See below)	Major

PART NO.
COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.1 Control valve ball failures preclude passageway for warm gas to applicable WPCA Turbo alternator.	Warm gas generator output directed to safety vent position. Affected PCD channel will not transfer warm gas to applicable WPCA Turbo alternator.	1) Control valve ball fractured.	High strength Titanium alloy (6AL-4V).	Major
		2) Obstruction in control valve ball transfer port.	Assembly/Quality Control function.	
		3) Control valve ball frozen in safe or other than arm position	Ball shaft mounted on New Hampshire ball bearings (2). High torque motor has to overcome frictional forces to drive (10 inch ounces).	
I.d.2 Control valve ball drive mechanism failures do not rotate ball from safe to arm position	"	1) Control valve shaft fractured.	CRES 416-Rockwell hardening C36-42.	Major
		2) Control valve shaft frozen.	New Hampshire bearings (dry) SFX 166PP on each end of haft.	
		3) Geneva star wheel shaft fractured	CRES 416-Rockwell hardening C36-42.	
		4) Geneva star wheel fractured	CRES 416-Rockwell hardening C36-42.	
		5) Geneva star wheel misaligned with drive pin.	Alignment assured by positive seatings of gears (shafts) to pre-drilled housing.	
		6) Drive pin fractured or not secured.	CRES 303 Cond. A - Pin staked at input end.	
		7) Geneva star wheel indexing gear to intermediate shaft fractured or misaligned	CRES 416-Rockwell hardening C32-38.	

PART NO.
COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SHEET 4 OF 8

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.2 (cont'd)		8) Geneva star wheel output shaft frozen	Mounted on New Hampshire bearing (dry) SF154-K25	
		9) Geneva star wheel intermediate shaft frozen.	Mounted on New Hampshire bearing (dry) SF154-K25	
		10) DC Motor failure.	Inland Corp. motor qualified on Remote Switch Driver-XM70.	
		11) DC Motor drive shaft fractured.	CRES 416 Rockwell hardening C32-38.	
		12) DC Motor drive shaft gear mis-aligned with mating gear.	Alignment assured by positive seating of gears (shafts) to predrilled housing.	
		13) DC motor drive shaft mating gear fractured.	CRES 416 Rockwell hardening C32-38.	
		14) Geneva output gear fractured.	CRES 416 Rockwell hardening C32-38.	

PART NO.
COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.3 DC Motor does not receive drive voltage to rotate control valve ball from safe to arm position		1) DC Motor (+) operational wiring or connector pin shorted or open (Good Separation circuit).	Wiring 24 gauge Teflon insulated. Connector MIL-C-38999	Major
		2) DC Motor (-) operational wiring or connector pin open.	Wiring 24 gauge Teflon insulated. Connector MIL-C-38999	Major
		3) DC Motor (+) Telemetry wiring shorts.	Wiring 24 gauge Teflon insulated.	

PART NO.

COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.4 DC Motor (+) circuit (Good Separation) not complete (open).	Affected PCD Channel Control Valve not rotated from safe to arm position, resulting in a "dudded" channel.	1) Enable mechanism contacts fail open.	Dual gold plated contactors. One contactor per each side of engaging blade.	Major
		2) Enable mechanism monitor switch disc fractures.	Contact blade molded into Epon Glass. Blade gold plated.	
		3) Control valve driver contacts fail open.	Dual gold plated contactors. One contactor per each side of engaging blade.	
		4) Control valve driver monitor disc fractures.	Contact blade molded into Epon Glass. Blade gold plated.	
I.d.5 Enable Mechanism failures prevent unlock of Control Valve Driver.	Affected PCD Channel control valve not rotated from safe to arm position resulting in a "dudded" channel	1) Enable mechanism (EM) Valve lock not secured to EM Drive Shaft.	Lock secured with hardened dowel pins CRES 440. Pins staked at both ends.	Major
		2) EM Drive Shaft fractured.	CRES 416 Rockwell hardening C36-42.	
		3) EM Drive Shaft frozen.	Mounted on New Hampshire bearings (dry) SF133K25 (2 ea.)	
		4) Either one of four Code Solenoids fails to function.	Same solenoids as used on demonstration EM model made for Picatinny, REI Model 2380.	
		5) Either one of two Code Probes frozen.	Mounted on CRES 440C lubricant impregnated (Microseal 100-1) dowels, press fit. Rockwell hardening to C53-58.	

PART NO.
COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.5 (Cont.)	"	6) Code Solenoid wiring or connector pin shorts or opens.	Wiring-24 gauge Teflon insulated. Connector MIL-C-38999.	
		7) Stepping Solenoid fails to function.	Solenoid a part of qualified Remote Switch Driver XM-70	
		8) Stepping Solenoid wiring or connector pin shorts or opens (Including telemetry wiring).	Wiring-24 gauge Teflon insulated. Connector MIL-C-38999.	
		9) Stepping Solenoid clapper frozen.	Mounted on CRES 440C lubricant impregnated (Microseal 100-1) dowels, press fit. Rockwell hardening C53-58	
		10) Stepping Solenoid clapper spring failed.	CRES 301 or 302 Condition C Precipitation hardened at 900°F. Stressed to 50% Max.	
		11) Stepping Solenoid clapper mechanical failure.	Carbon steel C1212 Cond. A	
		12) Stepping Solenoid clapper advancing pawl misaligned with Gear Train.	Alignment assured by positive seating of pawls to gear.	
		13) Gear Train misalignment.	Alignment assured by positive seating of gears (shafts) to pre-drilled housings.	
		14) Gear Train (8:1) fracture.	CRES 410	

PART NO.

COMPONENT Pneumatic Control Device

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

FAILURE MODE	EFFECT ON COMPONENT AND/OR SYSTEM	CAUSE OF FAILURE	REMARKS	CRITICALITY
I.d.5 (Cont'd)		15) Stepping Solenoid clapper mis-aligned with Output Shaft Limiter Cam.	Alignment assured by positive seating of cam and clapper to pre-drilled housings:	
		16) Shaft lock ball and pin frozen.	Ball-PIC AK-2 CRES 440 RC55-60. Pin - CRES 416 Rockwell hardening C36-42. Spring - CRES 301 or 302.	
		17) Racket wheel fractured.	CRES 440 Rockwell hardening C53-58.	
		18) Clutch inoper-ative.	Pinion aluminum bronze & CRES 440 Rockwell hardening C53-58.	
		19) Advancing pawl fracture	CRES 440 Rockwell hardening C53-58.	
		20) Advancing pawl spring failure	CRES 301 or 302 Stress 50% max. Condition C tempered.	

NOTE: DEFINITION OF CRITICALITY:

<u>Critical</u> - A failure that affects both PCD channels and prevents a warm gas generator output to the Warhead Power Converter Assembly (WPCA).

<u>Major</u> - A failure that affects and prevents only one PCD channel warm gas generator output to the WPCA.

<u>Minor</u> - A failure that <u>does not</u> affect either PCD channel warm gas generator output to the <u>WPCA</u> but does affect secondary features; e.g. telemetry.

APPENDIX B

EMI STUDIES AND TESTS

SYSTEMS DIVISION

201 LOWELL STREET, WILMINGTON, MASSACHUSETTS 01887

TECHNICAL REQUEST [ ] RELEASE [x]

ESDM-F440-0819

TO	DEPT.	FROM	DEPT.	DATE
V. Suozzo	F360	W. Lepsevich	F440	10/10/77

PROGRAM	WORK ORDER NO.	DATE INFO. NEEDED	REFERENCES
Pershing II/Raymond Eng. PCD			

SUBJECT

Preliminary EMI Testing - Arming Device

DISTRIBUTION

CENTRAL FILES

Pershing II Key Personnel

SIGNED W. Lepsevich

APPROVED

INFORMATION REQUESTED / RELEASED

Preliminary EMI testing was performed on a Raymond Engineering electromechanical arming device representative of the active part of the Pneumatic Control Device (PCD).

The results of these tests follow.

FORWARD

AVCO as subcontractor to Raymond Engineering has been responsible for guiding EMC of the PCD. To facilitate these efforts Raymond has provided an electromechanical arming device representative of the final design. Potential for conducted emissions from drive lines and any other identifiable EMI problems were to be identified.

The arming device was included in a demonstrator package which provided the proper sequence and drive signals. Since the clocking rate of the demonstrator was slow compared to the intended operation, a true modeling would not be ideal. Noting that the SACA breadboard was soon to be available, it was decided that waiting for it with the intention of using it to drive the PCD would provide a timely test for both units. An additional benefit of the microprocessor based SACA would be the case with which the arming routine could be looped to create a regenerative code without need for reset.

Due to time restrictions placed upon the Raymond demonstrator actual preliminary testing was limited to problem areas previously identified specifically conducted emissions and susceptibility. Results of that testing follows.

Equipment List

Electrometrics Analyzer, Model EMC - 25R4, Serial # 467
10KHz - 1GHz

Electrometrics Programmer, Model ESC-125A, Serial # 142

Electrometrics Interference Analyzer, Model EMC 10E, Serial # 523
20Hz - 50KHz

Stoddart Electro Syst Current probe, Model 91550-1, Serial # BF-196
30Hz - 100MHz

Hewlett Packard, VHF Generator, Model 608D, Serial # 1513

Stripline - AVCO 150KHz - 30MHz

Discussion of Tests:

Figure (1) shows the levels observed on the open drive line wires while performing the conducted emissions tests. Note that the three driver lines were collectively grouped and passed through the current probe. Throughout operation it can be seen that the observed levels remained considerably below those specified as limits for MIL-STD-461A (refer to corrected curve*).

In determining the susceptibility, the ability to couple into the circuit and cause malfunction was illustrated by placing the Arming device into a stripline generated electric field. Referring to Table (4), levels measured during testing indicated no significant coupling nor did the tests provide any malfunction of the SACA as a result of driving the arming device. As was anticipated, signals induced measured on the driver lines were significantly reduced once the mechanics of the arming device were grounded.

Conclusions:

Conducted emissions from the drive lines over the range of 10KHz thru 100MHz as tested, were well below those specified in MIL-STD-461A. It should be noted that during tests that the SACA driver was not truely saturating as was originally intended, thus allowing a soft turn-on and potentially fewer emissions. Despite this finding, it can be confidently stated that with the inclusion of recommendations by AVCO of shielded lines, enclosure, transient protection etc., further reductions in emissions are expected.

The modified susceptibility tests indicate no significant coupling modes although a slight sensitivity to orientation was noticed, the more susceptible position was found when the solenoid axis was perpendicular to the electric field generated. This was not found significant enough to effect any mechanical layout at this time although future consideration of extraordinary fields might take note. Since testing was performed on the unshielded device it can be concluded that shielding provided by an enclosure, emi filters and other EMI reduction techniques will enhance the figures of this test.

TABLE I

LABORATORY DATA SHEET

Driver line Conducted Emission Wideband

TITLE OF TEST

PCD - Represenative Enable mechanism

TEST WORK ORDER NO. | LABORATORY TEST PLAN NO. | DATA SECURITY CLASS

Raymond Eng.

Frequency	Attenuator	Ambient measurement	Attenuator	Dynamic Measurement			
10 KHz	0	-7db	60 db	+10 db			
20 KHz	0	-20db	60	+10			
30 KHz	0	-20db	60	+5			
40 KHz	0	-18db	60	+4			
50 KHz	0	-16db	60	+1			
60 KHz	0	-18db	60	0			
80 KHz	0	-16db	60	-5			
100 KHz	0	-10db	60	-10			
120 KHz	0	-15db	40	+5			
140 KHz	0	-14db	40	-1			
160 KHz	0	0	40	-7			
180 KHz	0	-13db	40	-5			
200 KHz	0	-7db	40	-5			
220 KHz	0	-8db	40	-6			
240 KHz	0	-14db	40	-8			
250 KHz	0	-17db	20	+8			
300 KHz	0	-17db	20	+8			
350 KHz	0	-12db	20	+9			
400 KHz	0	-12db	20	+10			
450 KHz	0	-12db	20	+10			
500 KHz	0	-12db	20	+9			
1000 KHz	0	-4db	20	+10			
2000 KHz	0	-8db	20	+4			
3000 KHz	0	+4db	20	+16			
4000 KHz	0	+12db	20	+18			
5000 KHz	0	+12db	20	+16			

REMARKS: Electrometrics EMC-25R4

Stoddart Elect Syst 91550-1 current probe

SACA · breadboard assy #1

TEST ENGINEER	DATE	TEST WITNESS	DATE	TEST WITNESS	DATE
J. Lepsevich					

TABLE 2

LABORATORY DATA SHEET

PAGE 2 OF

TITLE OF TEST: Driver line Conducted Emission Wideband

PCD - Represenative Enable Mechanism

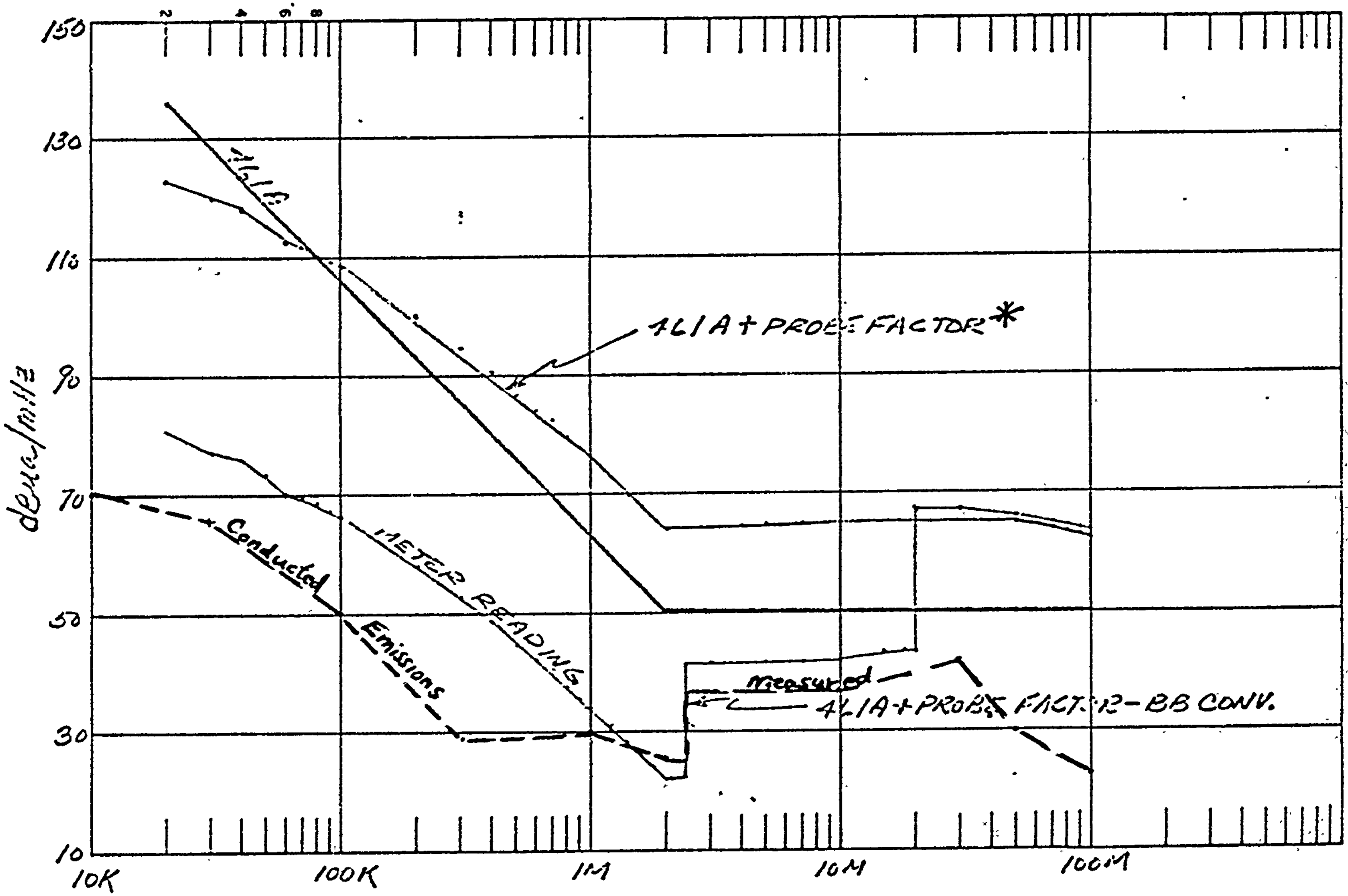
WORK ORDER NO.	LABORATORY TEST PLAN NO.	DATA SECURITY CLASS
Raymond Eng.		

Frequency	Attenuator	Ambient Measurement	Attenuator	Dynamic Measurement			
000 KHz	20	+2	20	+16			
10 MHz	20	0	20	+16			
15 MHz	20	-8	20	+10			
20 MHz	20	+3	20	+12			
25 MHz	20	-6	20	+9			
30 MHz	20	+10	40	0			
40 MHz	40	-11	40	-7			
50 MHz	20	+10	20	+10			
80 MHz	20	+2	20	+2			
100 MHz	20	0	20	0			

REMARKS:

TEST ENGINEER	DATE	TEST WITNESS	DATE	TEST WITNESS	DATE
J.J. Lepsevich					

91550-1 S/N



Comparison of CE Data against Probe Corrected limits of 461A*

FIGURE 1

NOTE: USE TYPE B PENCIL FOR VUGRAPHS AND REPORT DATA.

TABLE 3

METER READING - PROBE FACTOR & CONVERSION (BROADBAND) = SPEC. LIMIT

Current Probe, Model 91550-1 Serial BF196

Freq.	Limit 461A	Probe Factor	B.B. Conversion		Meter Limit
20 KHz	135	-11.5 = 123.5	43	=	80.5
30	127.5	- 8 = 119.5	43	=	76.5
40	123	- 5.5 = 117.5	42	=	75.5
50	118.5	- 3.7 = 114.8	42	=	72.8
60	115	- 3.0 = 112.0	42	=	70.0
70	112.5	- 1.0 = 111.5	42	=	69.5
80	110	0.2 = 110.2	42	=	68.2
90	107.5	1.2 = 108.7	42	=	66.7
100	106	2.0 = 108	42	=	66.0
200	93	6.8 = 99.8	42	=	57.8
300	85	9.1 = 94.1	42	=	52.1
400	80	10.2 = 90.2	42	=	48.2
500	75	11.1 = 86.1	42	=	44.1
600	72	11.7 = 83.7	42	=	41.7
700	70	12.0 = 82.0	42	=	40.0
800	67	12.2 = 79.2	42	=	37.2
900	64.5	12.7 = 77.2	42	=	35.2
1 MHz	63	12.9 = 75.9	42	=	33.9
1.2	59	13.2 = 72.2	42	=	30.2
1.4	56	13.4 = 69.4	42	=	27.4
1.6	54	13.6 = 67.6	42	=	25.6
1.8	51.5	13.7 = 65.2	42	=	23.2
2.0	50	13.7 = 63.7	42	=	21.7
2.1	50	13.7 = 63.7	42	=	21.7
2.2	50	13.8 = 63.8	42	=	21.8
2.3	50	13.8 = 63.8	42	=	21.8
2.4	50	13.9 = 63.9	42	=	21.9
3.0	50	14.0 = 64.0	23	=	41.0
5.0	50	14.2 = 64.2	23	=	41.2
7.0	50	14.4 = 64.4	23	=	41.4
10	50	14.5 = 64.5	23	=	41.5
15	50	14.6 = 64.6	22	=	42.6
18	50	14.7 = 64.7	22	=	42.7
20	50	14.7 = 64.7	22	=	42.7
30	50	14.6 = 64.6	-2	=	66.6
40	50	14.5 = 64.5	-2	=	66.5
50	50	14.3 = 64.3	-1	=	65.3
70	50	13.6 = 63.6	-1	=	64.6
80	50	13.1 = 63.1	-1	=	64.1
90	50	12.5 = 62.5	-1	=	63.5
100	50	12.0 = 62.0	-1	=	63.0

TABLE 4

LABORATORY DATA SHEET

PAGE 1 OF 1

Susceptibility (to a stripline generated field) Narrowband

TITLE OF TEST

PCD - Represenative Enable Mechanism

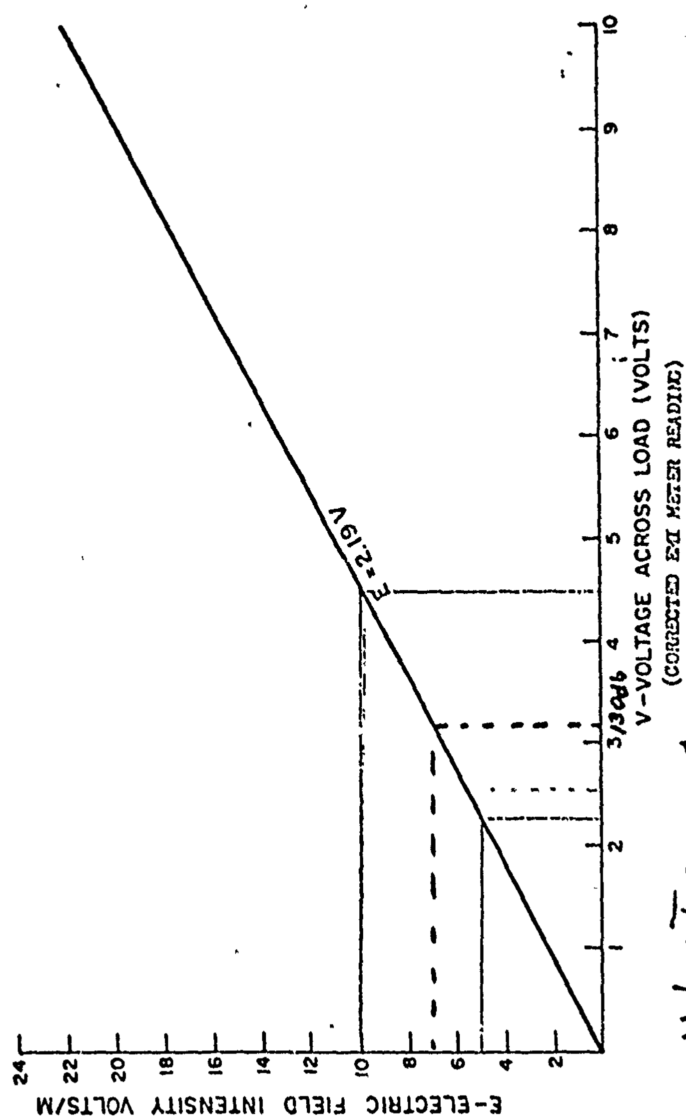
WORK ORDER NO.	LABORATORY TEST PLAN NO.	DATA SECURITY CLASS
Raymond Eng.		

Applied voltage	Electric field Intensity	Frequency	In Field — Current	out of field Probe —	W/Assy Gnded		
1db above 4V		50 khz	-6dbm				
00db	2volts/meter	100 khz	-8dbm	-8db			
db	2volts/meter	500 khz	24dbm	20db			
00db	2volts/meter	1000 khz	32db	25db			
db	2volts/meter	10 mhz	54db	46db	59db		
00db	2volts/meter	50mhz	44db	45db	42 db	← Fringing effects predominate	

Note: current probe clamped over 3 driver lines
Applied voltage was measured through an 82 Ω 30db pad
which must be included as part of Applied voltage.

REMARKS: AVCO Stripline - 150 khz - 30mhz
HP 608D -
Electrometrics EMC-25R4
Stoddart Elect Syst 91550-1

TEST ENGINEER	DATE	TEST WITNESS	DATE	TEST WITNESS	DATE
W.J. Lepsevich					



Note: Typical Calibration, Each Line must be individually calibrated

Figure RS04-4 - Line calibration chart

130db = 3.162 x10⁶ above 1µV
= 3.162 volts across load
≈ 2 volts/meter

FIGURE 2

Avco CORPORATION

AVCO SYSTEMS DIVISION

201 LOWELL STREET, WILMINGTON, MASSACHUSETTS 01887

TECHNICAL REQUEST [ ] RELEASE [X]

ESDM-F412-0932

TO	DEPT.	FROM	DEPT.	DATE
V. Suozzo	F360	W. Lepsevich	F412	12/30/77

PROGRAM	WORK ORDER NO.	DATE INFO. NEEDED	REFERENCES
Pershing II/Raymond Eng. PCD			

SUBJECT

EMC (Electromagnetic Compliance)

DISTRIBUTION	
Pershing II Key Personnel	SIGNED W. Lepsevich
	APPROVED Leo Roy

INFORMATION REQUESTED / RELEASED

Avco in a continuing effort to monitor Electromagnetic compatibility (EMC) of the Pneumatic Control Device (PCD) makes the following final recommendations of this phase.

Representative models of the PCD have suggested that compliance with MIL 461A at the driving levels and speeds experienced when driven with the SACA prototype can be realized. An attempt to soften the back-emf generated, at the PCD itself should remain the prime concern. Raymond Engineering has met the problem in the past with a compensating (energy absorbing) RC combination picked for that particular driven coil. Realizing that this combination can become bulky physically when finally arrived at, it is suggested that Transient Protection Devices (TPD) of the semiconductor variety together with a reverse biased diode provide a similar function with a savings in size and a compatibility with all coil designs. Recent devices by Unitrode Corp. provide a timely selection of devices designed for this purpose. (Attachment I)

Future comments will use the results of additional testing in later phases where configurations closer resembling the final design come into being. Present models would indicate that an attempt to "shave" bulk from the final versions is necessary and would have an immediate effect of altering the shielding effect now provided by the present approach. Monitoring future designs for EMC is strongly suggested.

TRANSIENT VOLTAGE SUPPRESSORS

for Microprocessor and IC Protection Applications

TVS505
TVS528

FEATURES

- 500W for 1mS Pulse Power Capability
- Clamping Time of 1 x 10 seconds
- Direct Applicability for all popular Microprocessors and IC families
- Metallurgically bonded assembly system to assure long term reliability
- Miniature glass encased hermetically sealed package

DESCRIPTION

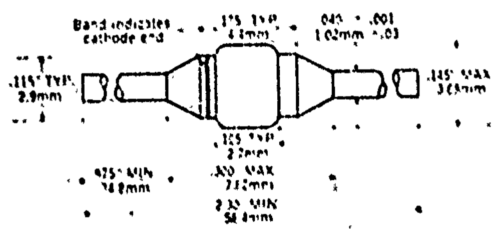
Unitrode's TVS505 series of transient voltage suppressors features oxide passivated zener type chips with full faced metallurgical bonds on both sides to achieve high surge capability and negligible electrical degradation under repeated surge conditions. The series is especially useful in protecting microprocessor, MOS, CMOS, TTL, Schottky TTL, ECL, I²L and linear integrated circuits from spurious transient disturbances.

ABSOLUTE MAXIMUM RATINGS @ 25°C

Stand-off Voltage, V.	5.0V to 28.0V
Breakdown Voltage	See Table
Forward Surge Current (8.3 mSec half sinewave)	50A
Peak Pulse Current	See Table
Peak Pulse Power	See Graphs
Power, Continuous	5W
Storage and Operating Temperature	-65°C to +175°C

MECHANICAL SPECIFICATIONS

TVS505 Series BODY B

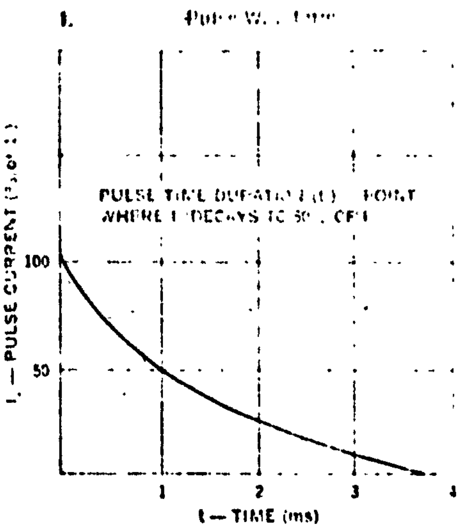


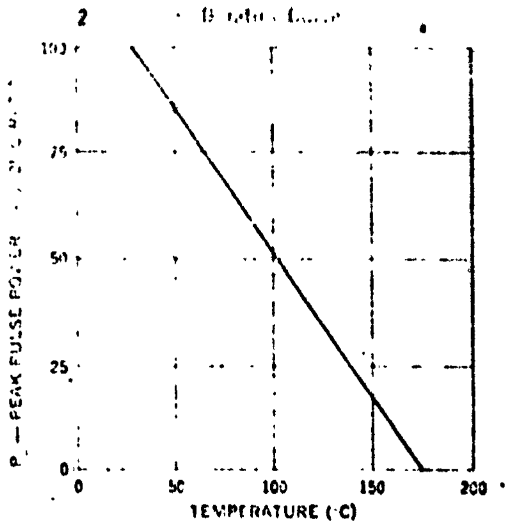
ELECTRICAL SPECIFICATIONS @ 25°C

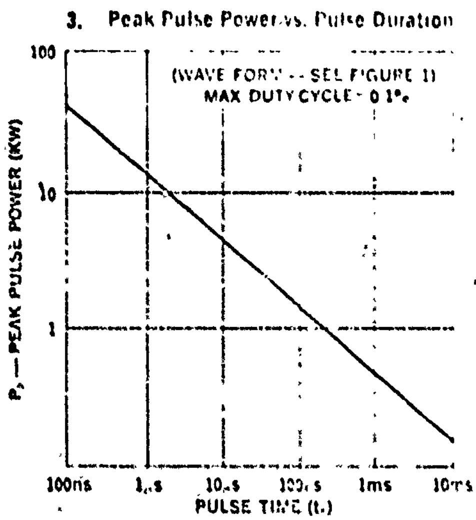
TVS Part No. B Package	Stand-Off Voltage V_s Volts	Min. Breakdown Voltage BV @ 1mA Volts	Max. Leakage Current I_L @ V_s μA	Max. Clamping Voltage V @ 1A Volts	Max. Clamping Voltage V @ 5A Volts	Max. Clamping Voltage V @ 10A Volts	Max. Peak Pulse Current I Amps	Max. Clamping Voltage V @ I Volts
TVS 505	5.0	6.0	300	7.4		7.9	53.7	9.3
TVS 510	10.0	11.1	5	13.2		14.4	30.3	16.5
TVS 512	12.0	13.8	5	16.5		18.5	23.8	21.0
TVS 515	15.0	16.7	5	19.7		22.2	19.8	25.2
TVS 518	18.0	20.4	5	23.8	[illegible]		[illegible]	32.5
TVS 524	24.0	[illegible]	5	32.4	37.0		11.9	42.5
TVS 528	28.0	[illegible]	5	35.9	41.0		10.7	[illegible]

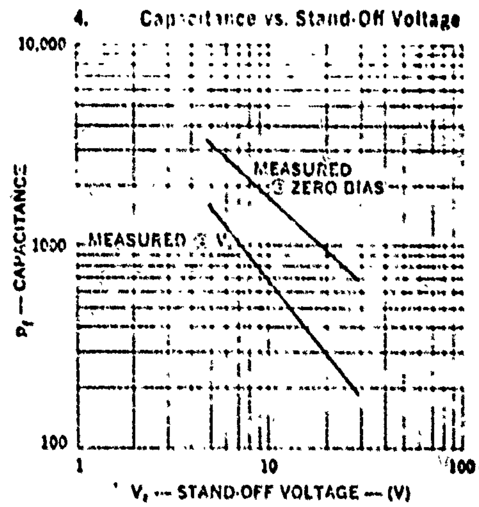
4/77A

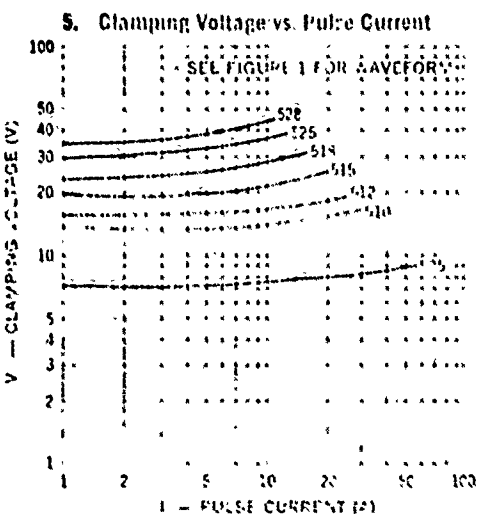
UNITRODE

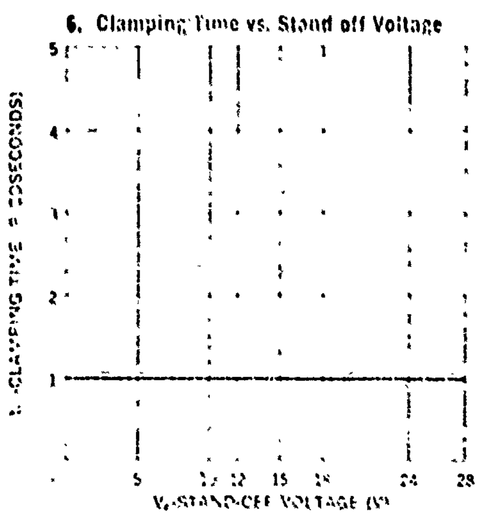

1.
PULSE TIME DURATION (t) ... POINT WHERE I DECAYS TO 50 ... OF I
I — PULSE CURRENT
100
50
1
2
3
4
t — TIME (ms)


2
75
50
25
0
P — PEAK PULSE POWER
0
50
100
150
200
TEMPERATURE (°C)


3. Peak Pulse Power vs. Pulse Duration
(WAVE FORM — SEE FIGURE 1)
MAX DUTY CYCLE — 0.1%
100
10
1
P — PEAK PULSE POWER (KW)
100ns
1ms
10ms
PULSE TIME


4. Capacitance vs. Stand-Off Voltage
10,000
1000
100
MEASURED
ZERO BIAS
MEASURED
CAPACITANCE
1
10
100
STAND-OFF VOLTAGE — (V)


5. Clamping Voltage vs. Pulse Current
100
50
40
30
20
10
5
4
3
2
1
1
2
5
10
100
PULSE CURRENT


6. Clamping Time vs. Stand off Voltage
5
4
2
1
5
12
15
24
28
STAND-OFF VOLTAGE

APPLICATION NOTE

INTRODUCTION

During transient periods, circuit voltages and currents are often many times greater than their steady state values and, therefore, must be considered in overall electronic system design in order to ensure required circuit performance and reliability, during both the transient duration and after transient occurrence (steady state).

Transients may result from a variety of causes such as normal switching operations, i.e., power supply turn-on and turn off cycles, routine AC lines fluctuations due to changing power requirements of heavy industrial equipment or abrupt circuit disturbances such as faults, voltage dips, magnetic coupling by electro mechanical devices, and lightning surges. With the increasing usage of microprocessors and associated integrated circuits (RAMs, ROMs, pROMs, I/O devices) the question of transient voltage protection must be considered by circuit and system designers. Voltage transients are a major cause of component failure in semiconductor circuit applications. Random high voltage transient spikes can permanently damage these voltages-sensitive devices or disrupt proper system operation. Catastrophic power supply conditions are not necessarily what should concern the designer most — just normal power supply on off cycles have the potential of emitting spikes of sufficient energy content to blow out an entire device chain. Surviving devices are then suspect and may be only marginally effective or show degraded performance. Troubleshooting, isolating and replacing damaged devices is obviously time consuming and very costly, especially when performed in the field.

While most microprocessor and IC semiconductor manufacturers design some form of diode-resistive input clamping network on the chip itself, transient voltage protection offered is very minimal — on the order of several watts. Manufacturers are also reticent in making device performance and reliability claims when power supply operation extends beyond the maximum rated level of the individual device family for even relatively short durations such as those that may be encountered during on-off transitions. The need for some protective device to suppress voltage transient is, therefore, indicated.

Unitrode's TVS 505 series of transient voltage suppressors offers the designer significant price-performance advantages over competing protection methods. Their miniature size permits simple installation on "close-in" or distributed system protection applications such as in the case where circuit boards are dispersed throughout an electronic rack or large enclosure. Dispersed usage aids in system troubleshooting and also affords extended transient voltage protection coverage where the likelihood exists for internal system disturbances, such as those caused by relay or coil driven mechanisms, where large current transients can be induced to adjacent logic circuitry.

In spite of its small size, the TVS 505 suppressor series is capable of dissipating [illegible] watts peak pulse power for a 1 millisecond duration. Response time to transients is near instantaneous — about 1 x [illegible] seconds. The series also exhibits both low and repeatable clamping factors throughout the performance range.

TRANSIENT VOLTAGE SUPPRESSOR CHARACTERISTICS

Unitrode's TVS 505 series has been devised to allow for ease of selection as a system element. It is instructive to outline salient device specification parameters.

STAND OFF VOLTAGE

The proper device is selected in conjunction with the nominal power supply voltage level of the application. For example, to suppress transient voltages from a 5-volt logic power supply, a device with a stand-off voltage, V , of 5 volts is chosen. Stand-off voltages other than those indicated in the specification table can be provided.

MAXIMUM LEAKAGE CURRENT

Maximum Leakage Current, I , is measured at V to indicate maximum expected current drain by the TVS element. While often much lower in actuality than indicated in the specification table, leakage current selection can be performed at the factory to assure lower leakage current for critical applications.

MINIMUM BREAKDOWN VOLTAGE

The minimum device breakdown voltage, designated by BV (min), corresponds to the point at which voltage clamping is initiated and incorporates application design factors relating to user power supply regulation tolerances as well as system operating temperature considerations. This parameter is measured at a test current of 1 mA.

MAXIMUM CLAMPING VOLTAGE

Maximum Clamping Voltage, V , represents the maximum peak voltage appearing across the device when subjected to a surge current for a 1 millisecond time duration. Clamping voltage is normally specified at maximum rated peak pulse current for the specific device, but is also provided at intermediate pulse current levels. The peak pulse current is defined as an exponential waveform. See Figure (1).

APPENDIX C

NUCLEAR EFFECTS STUDY

AND

HUMAN FACTORS ENGINEERING

AVCO CORPORATION

AVCO SYSTEMS DIVISION

201 LOWELL STREET, WILMINGTON, MASSACHUSETTS 01887

TECHNICAL REQUEST [ ] RELEASE [x]

ESDM-F412-0931

TO	DEPT.	FROM	DEPT.	DATE
V. Suozzo	F360	W. Lepsevich	F412	12/30/77

PROGRAM	WORK ORDER NO.	DATE INFO. NEEDED	REFERENCES
Pershing II/Raymond Eng. PCD			

SUBJECT

Nuclear V & H Conclusions

DISTRIBUTION	
Pershing II Key Personnel	SIGNED W. Lepsevich
	APPROVED Leo Roy

INFORMATION REQUESTED / RELEASED

TECHNICAL REQUEST/RELEASE	FROM W. Lepsevich	Page 2 of 2 DATE 12/30/77

In reviewing present prototypes of the Pneumatic Control Device (PCD) the following explicit final recommendations are to be mentioned to assist in the production of a satisfactorily hard (nuclear) component:

(1) Neutron and Gamma levels suggest that in any RC circuit (that might be used to soften the back emf of the solenoids) used, ceramic type capacitors be used with carbon resistors. If a Transient Protection Device (TPD) is used it should be selected with a times three safety factor for its power rating and degradation in stand off voltage be allowed for. In attachment I of this document a recent data sheet from Unitrode provides additions to those devices previously recommended with many lower voltage types now available in the 5 watt category.

(2) To reduce emission levels from internal surfaces, that they be treated with a low z material.

(3) Circuit impedances be kept low (below 200 Ω).

(4) Good grounding surfaces be stressed in the final configuration to assist in removing replacement currents.

(5) Teflon as an insulator and Gold as a conductor be avoided as materials.

(6) There are no obvious difficulties in the present winding method or encapsulating techniques.

(7) Core material will not be seriously effected by the environments to be experienced.

TRANSIENT VOLTAGE SUPPRESSORS

for Microprocessor and IC Protection Applications

FEATURES

- 500W for 1mS Pulse Power Capability
- Clamping Time of 1 x 10[illegible] seconds
- Direct Applicability for all popular Microprocessors and IC families
- Metallurgically bonded assembly system to assure long term reliability
- Miniature glass encased hermetically sealed package

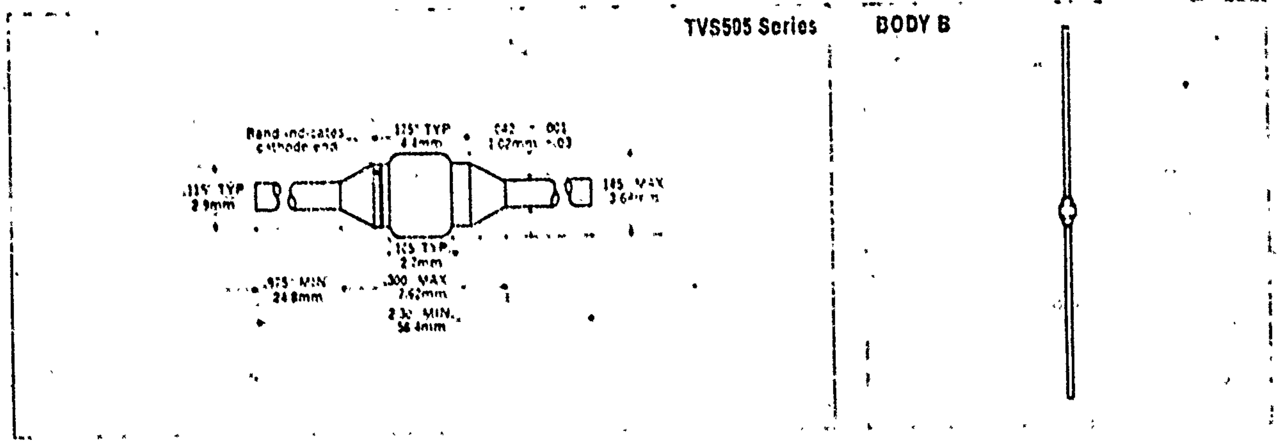
DESCRIPTION

Unitrode's TVS505 series of transient voltage suppressors features oxide passivated zener type chips with fully faced metallurgical bonds on both sides to achieve high surge capability and negligible electrical degradation under repeated surge conditions. The series is especially useful in protecting microprocessor, MOS, CMOS, TTL, Schottky TTL, ECL, I L and linear integrated circuits from spurious transient disturbances.

ABSOLUTE MAXIMUM RATINGS @ 25 C

Stand-off Voltage, V	5.0V to 28.0V
Breakdown Voltage	See Table
Forward Surge Current (8.3 mSec half sinewave)	50A
Peak Pulse Current	See Table
Peak Pulse Power	See Graphs
Power, Continuous	5W
Storage and Operating Temperature	−65 C to +175 C

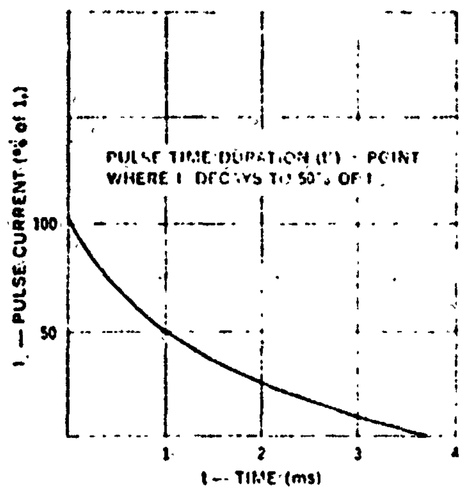
MECHANICAL SPECIFICATIONS



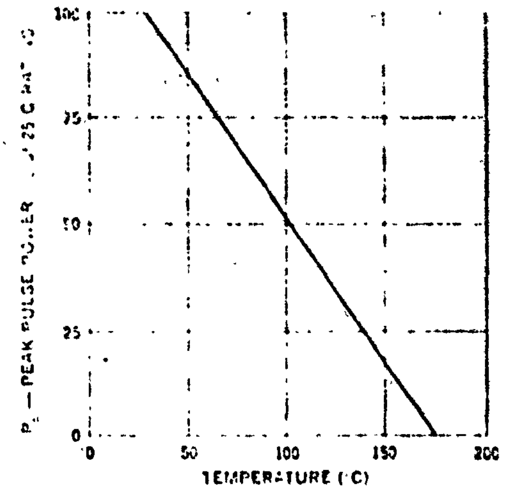
ELECTRICAL SPECIFICATIONS @ 25 C

TVS Part No. B Package	Stand-Off Voltage V_s Volts	Min. Breakdown Voltage BV @ 1mA Volts	Max. Leakage Current I_L @ V_s µA	Max. Clamping Voltage V @ 1A Volt	Max. Clamping Voltage V @ 5A Volts	Max. Clamping Voltage V @ 10A Volts	Max Peak Pulse Current I_p Amps	Max. Clamping Voltage V @ I_p Volts
TVS 505	5.0	6.0	300	7.4		7.9	53.7	9.3
TVS 510	10.0	11.1	5	13.2		14.4	30.3	16.5
TVS 512	12.0	13.8	5	16.5		18.5	23.8	21.0
TVS 515	15.0	16.7	5	19.7		22.2	19.2	[illegible]
TVS 518	18.0	20.4	5	22.5	26.0		[illegible]	[illegible]
TVS 524	24.0	28.4	5	32.4	37.0		11.9	42.0
TVS 528	28.0	30.7	5	[illegible]	41.0		10.7	[illegible]

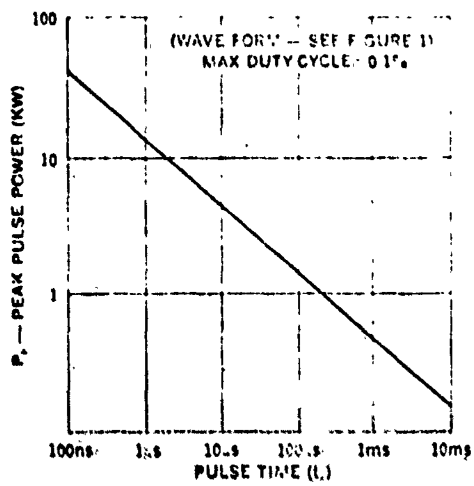
1. Pulse Waveform



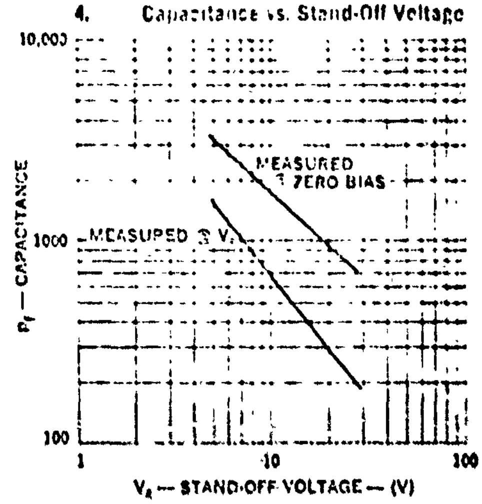
2. Derating Curve



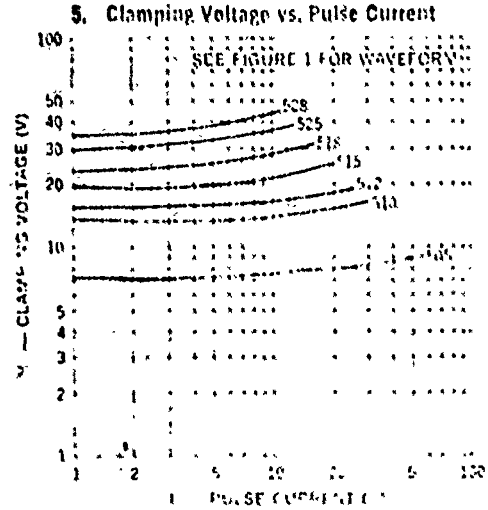
3. Peak Pulse Power vs. Pulse Duration



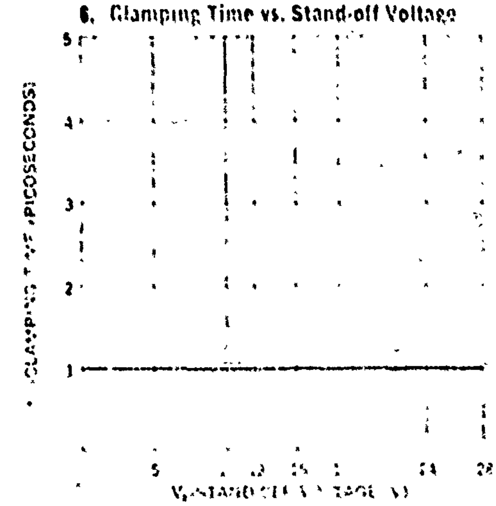
4. Capacitance vs. Stand-Off Voltage



5. Clamping Voltage vs. Pulse Current



6. Clamping Time vs. Stand-off Voltage



APPLICATIONS NOTES

INTRODUCTION

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While most microprocessor and IC semiconductor manufacturers design some form of diode-resistive input clamping network on the chip itself, transient voltage protection offered is very minimal — on the order of several watts. Manufacturers are also reticent in making device performance and reliability claims when power supply operation extends beyond the maximum rated level of the individual device family for even relatively short durations such as those that may be encountered during on-off transitions. The need for some protective device to suppress voltage transient is, therefore, indicated.

Unitrode's TVS 505 series of transient voltage suppressors offers the designer significant price performance advantages over competing protection methods. Their miniature size permits simple installation on "close-in" or distributed system protection applications such as in the case where circuit boards are dispersed throughout an electronic rack or large enclosure. Dispersed usage aids in system troubleshooting and also affords extended transient voltage protection coverage where the likelihood exists for externally induced system disturbances, such as those caused by relays or solenoid-driven mechanisms, where large current transients can be induced to adjacent logic circuitry.

In spite of its small size, the TVS 505 single-series is capable of dissipating 500 watts peak pulse power for a 1 millisecond duration. Response time to transients is near instantaneous — about 1 x 10 [illegible] seconds. The series also exhibits both low and repeatable clamping factors throughout the performance range.

TRANSIENT VOLTAGE SUPPRESSOR CHARACTERISTICS

Unitrode's TVS 505 series has been devised to allow for ease of selection as a system element. It is instructive to outline salient device specification parameters.

STAND-OFF VOLTAGE

The proper device is selected in conjunction with the nominal power supply voltage level of the application. For example, to suppress transient voltages from a 5-volt logic power supply, a device with a stand-off voltage, V_s, of 5 volts is chosen. Stand-off voltages other than those indicated in the specification table can be provided.

MAXIMUM LEAKAGE CURRENT

Maximum Leakage Current, I_L, is measured at V_s to indicate maximum expected current drain by the TVS element. While often much lower in actuality than indicated in the specification table, leakage current selection can be performed at the factory to assure lower leakage current for critical applications.

MINIMUM BREAKDOWN VOLTAGE

The minimum device breakdown voltage, designated by BV (min), corresponds to the point at which voltage clamping is initiated and incorporates application design factors relating to user power supply regulation tolerances as well as system operating temperature considerations. This parameter is measured at a test current of 1 mA.

MAXIMUM CLAMPING VOLTAGE

Maximum Clamping Voltage, V_C, represents the maximum peak voltage appearing across the device when subjected to a surge current for a 1 millisecond time duration. Clamping voltage is normally specified at maximum rated peak pulse current for the specific device but is also provided at intermediate pulse current levels. The peak pulse current is defined as an exponential wave form. See Figure (1).

Introduction.

The design of the Pneumatic Control Device (PCD) Preliminary Operational Model (POM) has been reviewed from the Human Engineering standpoint. The purpose of the review was to ensure that the PCD design has considered ease and safety of operation while the device is being utilized during development and test.

Discussion.

Of prime concern to human safety is the operation of the warm gas generator which emits a flame of up to +2100°F for   seconds when activated.

As a component (prior to installation in the PCD) an inadvertent activation of the warm gas generator could cause personnel injury. As a personnel safety precaution during handling, a means for shorting (shunting) the generator initiator leads is provided to preclude initiation from external sources such as static electricity.

With the gas generators installed in the PCD and the control valve in the "SAFE" position an electrical short (shunting) of the initiators is provided on the control driver rotary switches. This provision provides protection against an inadvertent activation if sufficient electrical energy were available to the gas generator initiators under a fault condition.

With the control valve rotated between the "SAFE" and "ARM position the initiators remain shorted. If a failure occurred in the PCD resulting in inadvertent initiation, release of the gas, blocked from exiting the safety port and transfer tube, would be through a blowout plug on the generator allowing mass dispersion of the warm gas in a safe manner.

An added safety feature of the PCD is a "SAFE" and "ARM" indicator located at the control valve ball location. This indicator provides positive visual means for personnel to determine control valve position and initiator shorting status.

Future Development.

In further fabrication of the FCD, human factors will continue to monitor the warm gas generator during handling, installation and test. Additional consideration will be given to assure protection against human error; i.e., improper installation of gears, cam lock devices, code wheels, shafts, clutches, solenoids, and electrical contacts.

APPENDIX D

REENTRY SENSOR - SAFETY ANALYSIS

APPENDIX E

BALL VALVE - WEDGE ANALYSIS

(1) With a 15° wedging angle it can be shown that the lateral-acting "keeper" balls will act as one-way locks on the vertical valve stem. Specifically, wedge movement would be reversible for sufficiently high reverse thrust from the valve only if friction at each wedge face remained below a .13 coefficient value. For steel-on-steel (or titanium) sliding friction would most probably exceed this level.

(2) Similarly, the 7° ball seat wedge angle would theoretically require friction coefficient below .06 in order that sufficiently high pressure be able to reverse wedging action. Though such low friction levels seem extremely unlikely, it has, in fact, proved necessary to provide a 60 pound valve stem forward force to maintain a pressure seal (this, versus an 18-to 25 pound maximum reverse force component due to pressure). In all probability, initial pressure leaks result from the slightest imperfections at the input seat, where internal (pressure) forces initially tend to open the seat seal. When the currently open viewing window eventually is closed on the valve chamber, the secondary seals already present in the design could obviate the leakage tendency as chamber pressure equalizes to internal passage pressure. This would, in turn, reduce the valve stem seating force requirement.

(3) With reference, again to the 15° "keeper" wedge, the attached sketch is meant to serve as a convenient example to establish that, even in the presence of irreversible (one-way acting) wedging, repetitive applied forces do not lead to cumulative build-up of locking stresses. (a) Wedge spring force (F) is initially sized to move the wedge laterally so as to establish a 1000 pound (assumed arbitrarily) vertical load on the ball seat. (b) If an additional 5 pound force is subsequently applied to the ball, the following scenario ensues: The added 5 pound can not of itself add to ball seat loading since exceeding the existing 1000 pound seat load would imply further seat deflection, which would, in turn, unload the wedge, requiring at least an additional 1000 pounds. Rather, the wedge load simply reduces to 995 pounds, so that spring force (F) becomes unbalanced and moves the wedge deeper to the left to reestablish a 1000 pound reaction force at the ball. This requires downward shift of the ball and therefore additional deflection of the ball seat, which now becomes loaded to a total of 1005 pounds. (c) The 1005 pound seat load remains when the 5 pound ball load is removed, assuming irreversibility of wedging action. Wedge reaction force, moreover, jumps up to balance the 1005 pound seating load. (d) If up to 5 pound is now reapplied to the ball, no further loading occurs since wedge reaction drops only to 1000 pounds, at or beyond which the spring force (F) is unable to advance the wedge further. The 5 pound initial "surcharge" thus becomes a loading threshold. It can be

seen that the maximum surcharge equates to the one-shot peak level of extraneous additional (shock or vibration) loading. Furthermore, if the initial (wedge spring induced) seat load is quite high relative to such extraneous subsequent peaks, the surcharge effect will tend to be insignificant.

Fig 1a.

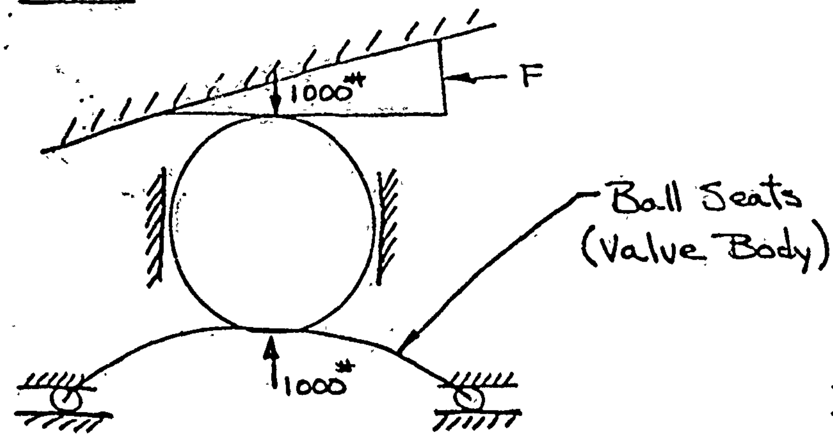


Fig 1b

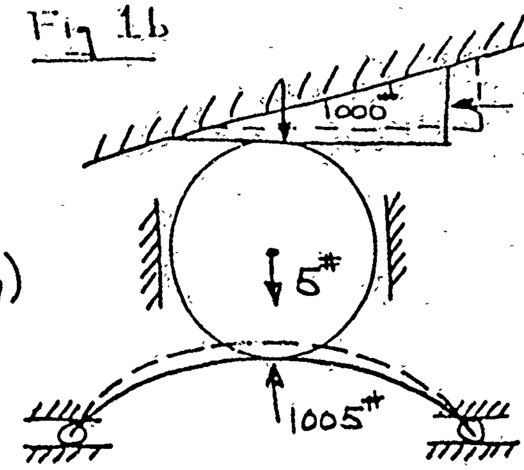


Fig 1c

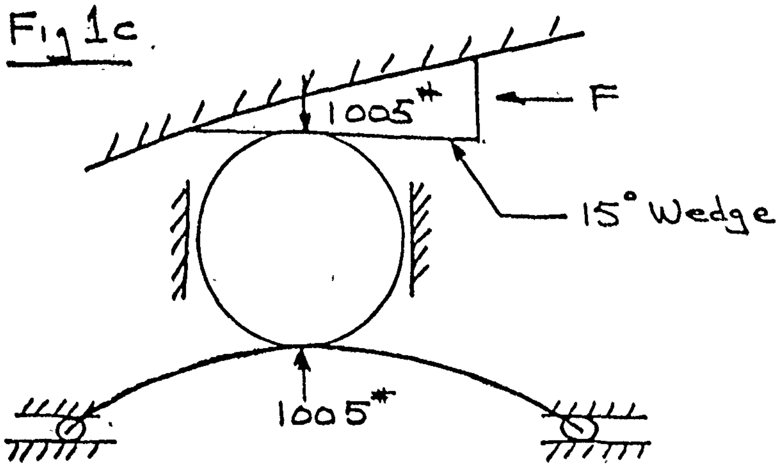
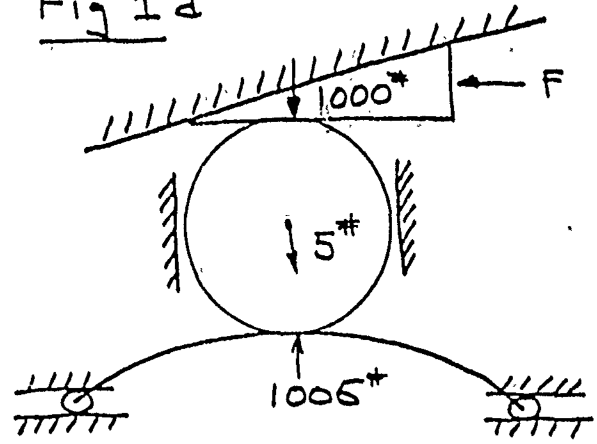


Fig 1d



Variations, within drawing limits, of parts will be compensated for because location of the weld head is based on the actual part being welded.

Receiving, manufacturing and assembly inspections will occur at appropriate points throughout the program. The following charts (with notes) show the flow of parts and assemblies through inspection points, and the proper chain of events when parts or assemblies are rejected.

Reentry Sensor - System Safety Analysis.

The reentry sensor recieves its solenoid unlock signal late in the missile flight (T_{co}+375 s), Prior to T_{co}+375, two simultaneous faults have to occur for a premature output. First SACA functional power must be supplied prematurely (normal time also T_{co}+375s), and secondly a fault must occur within the reentry sensor. Sensor failures hypothesized are: 1) input/output wire shorts (Y8), or 2) contacts failing closed (e.g. contamination)(Y9). These combined failures would bypass power around the normally open switch of the sensor. The sensor faults in existence after normal functional power is applied to the sensor would result in bypassi the reentry sensor function if reentry deceleration was not attained. These failure are considered to be most critical hypothesized. Additional fault paths for premature output requires additional coexisting faults.

The failure modes discussed can be eliminated or controlled by 1) isolating input/output switch wires from each other; and 2) by providing sufficient spacing between switch contacts to preclude most commonly encountered contaminants.

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS

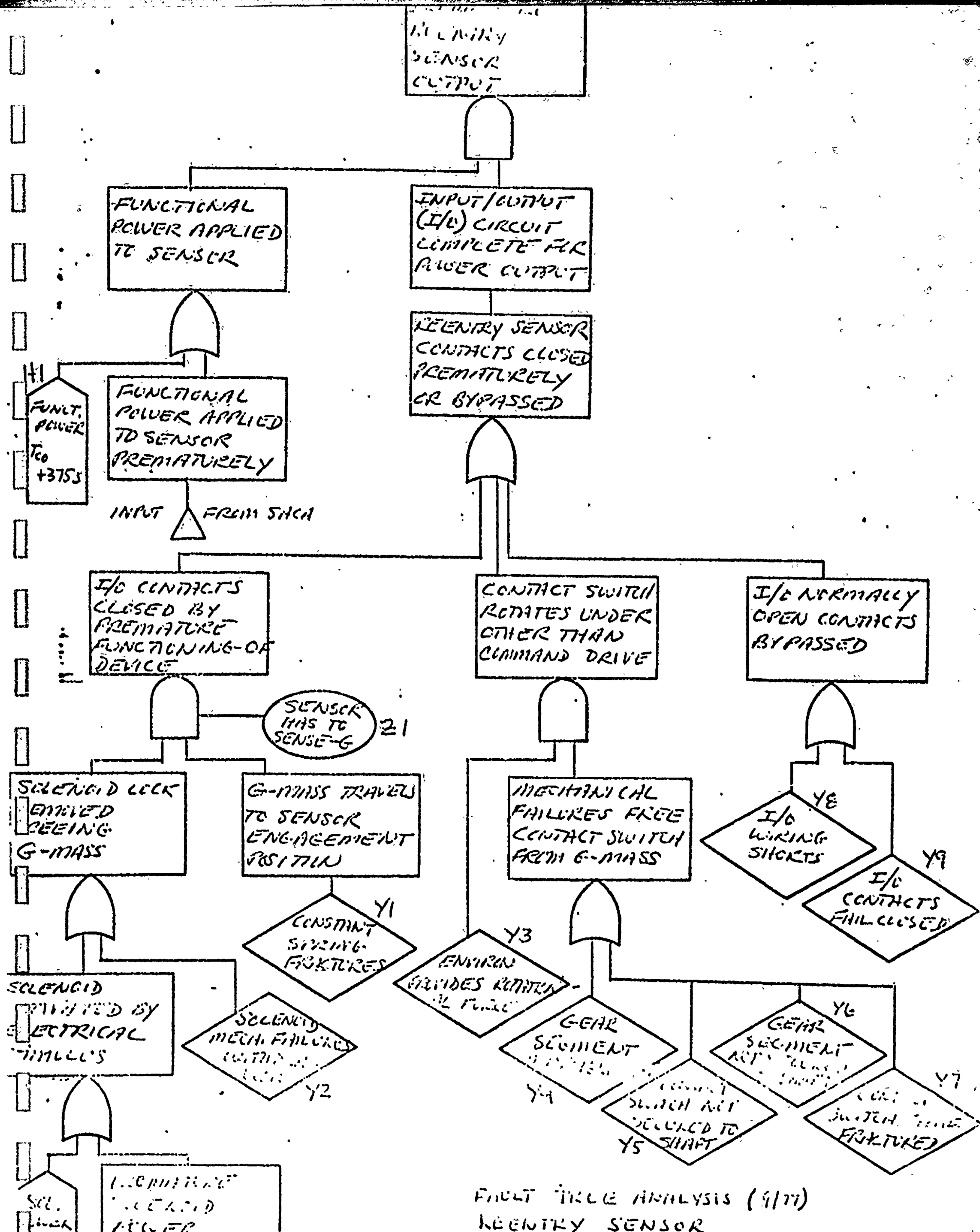
SUBSYSTEM - Reentry Sensor

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
Solenoid.	Prevents "g" mass movement until enabled during reentry phase of flight.	Solenoid arm.	Mechanical failures allow withdrawal of "g" mass block (Y2).	G mass free to respond to -g environment.	I	Additional failure required before g mass would activate sensor prematurely.
G-Mass.	Provide energy to rotate normally open contacts to closed position upon sensing proper reentry acceleration environment.	Constant spring.	Fracture (Y1).	G mass would rotate normally open contacts to closed position if -g's sensed.	II	G mass would activate sensor upon release of solenoid block before or without attaining the desired -g loading. Device cannot function under normal conditions prior to reentry phase.
Contact Switch Mechanism.	Provide electrical path upon switch closure at desired reentry deceleration phase.	Gear Segment.	Misalinged with pinion (Y4).	Contact switch free to rotate.	II	Failure mode combined with shock or vibration (Y3) during flight could conceivably rotate contacts to closed position prematurely with solenoid block still in place.
			Not secured to shaft (Y6).	"	II	"

FAILURE MODE AND HAZARDOUS EFFECTS ANALYSIS

SUBSYSTEM - Reentry Sensor

SUBCOMPONENT	SUBCOMPONENT FUNCTION	MECHANISM	MECHANISM FAILURE MODE	FAILURE EFFECT ON SUBSYSTEM	HAZARD CLASSIFICATION	SAFETY FEATURES/REMARKS
		Contact Switch.	Shaft fracture (Y7).	"	II	"
			Not secured to shaft (Y5).	"	II	"
Interconnections.	Internal reentry sensor wiring providing electrical connection to sub components.	Wiring and connections.	Input/output contacts fail closed (contamination) (Y9).	Reentry sensor normally open contacts bypassed resulting in premature activation.	II	Power applied to reentry sensor would be diverted out resulting in a premature output regardless of mission phase. These potential failure modes must be isolated to meet the "no single failure" design criteria.
			Input/output wiring shorts (Y8).	"	II	"



FAULT TREE ANALYSIS (9/77)
REENTRY SENSOR

FIGURE 1-6

APPENDIX E

BALL VALVE - WEDGE ANALYSIS

BALL VALVE WEDGE ANALYSIS

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Fig 1a

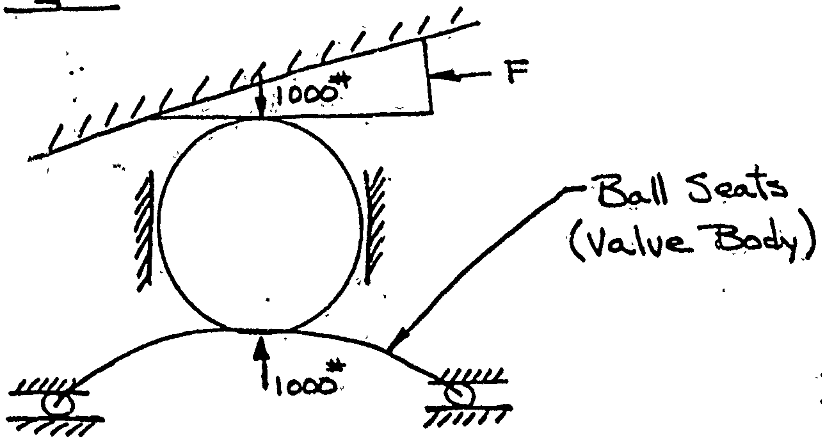


Fig 1b

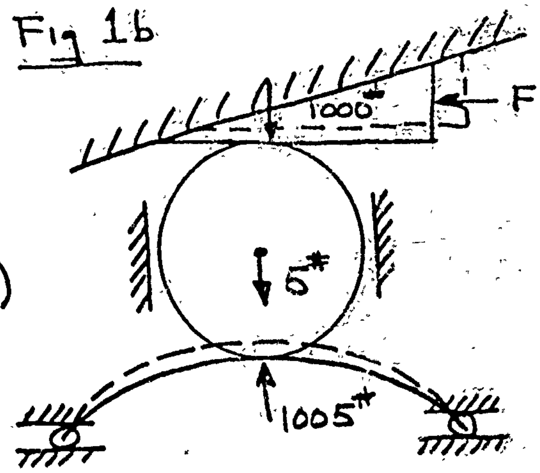


Fig 1c

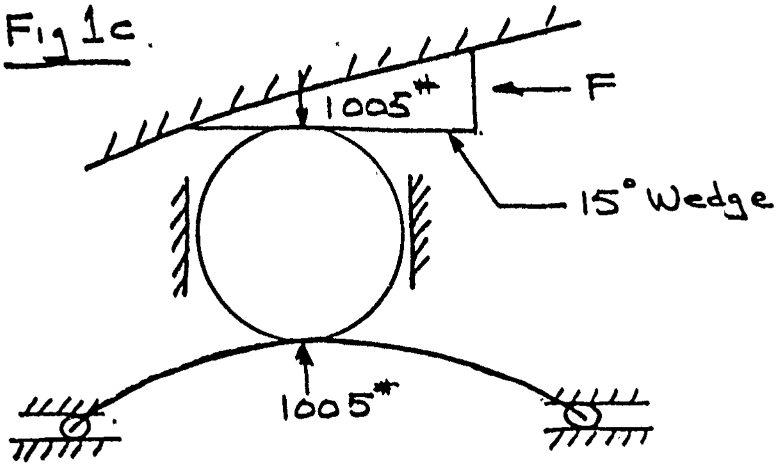
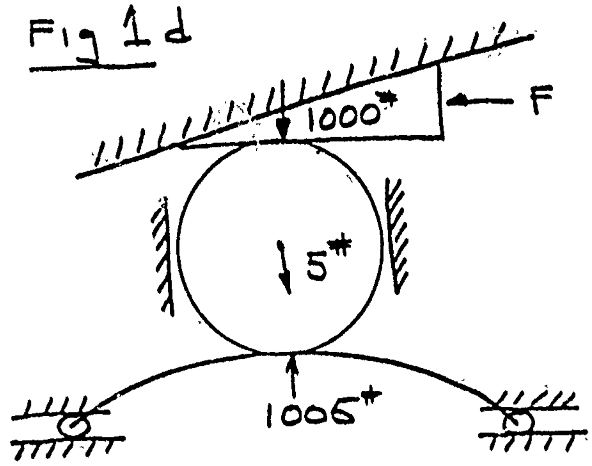


Fig 1d



APPENDIX F

THERMAL ANALYSIS OF HOT GAS FLOW SYSTEM

2.0 DESCRIPTION OF GAS-SUPPLY SYSTEM

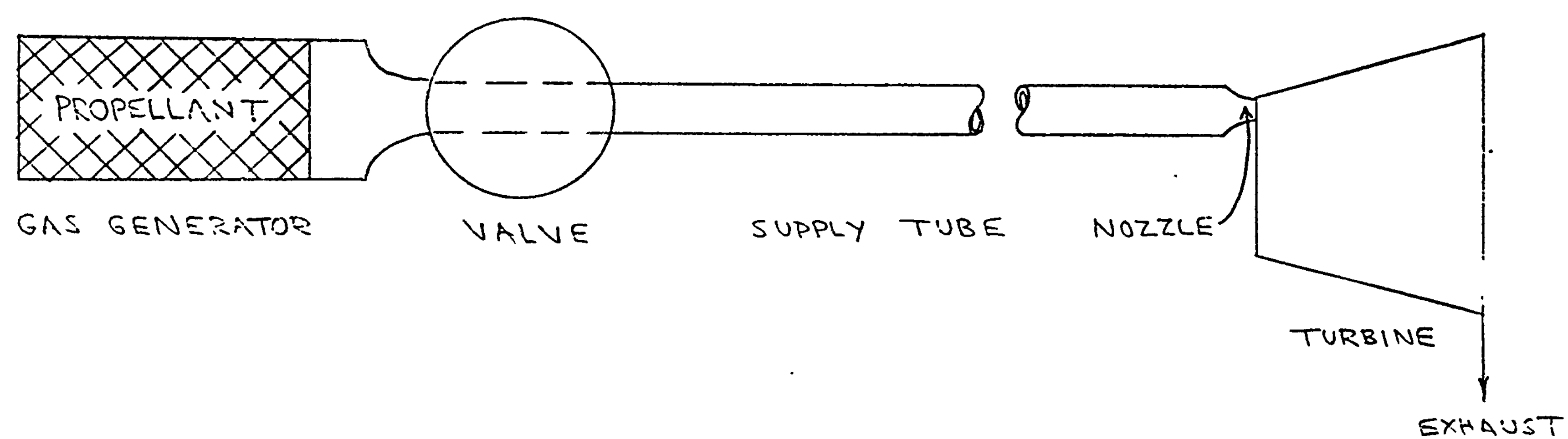
The major components of the gas-supply system are shown schematically in Figure 1. The entire system is initially "soaked-out" at an ambient temperature which may range from -29 to +125 F. When power is required, the gas generator is ignited and supplies hot gas through the valve, supply tube, and nozzle to the turbo-generator. In order to accelerate the turbo-generator rapidly, a high gas flow is used to produce high power during a 5-second boost phase, after which the gas flow is reduced to a lower value for the approximately 60-second sustain phase. The required gas horsepower at the nozzle is shown in Figure 2*. While high gas temperature is of course desirable, since for a given gas-flow rate the gas horsepower

$$GHP = \frac{1545}{550} w_2 \frac{2}{2-1} \frac{T_2}{\bar{M}_2} \left[1 - \left(\frac{P_e}{P_2}\right)^{\frac{2-1}{2}} \right]$$

---

*It was not clearly specified by Raymond Engineering during the course of the work reported here whether the requirement was to produce the two GHP vs time traces as shown for the two extreme ambient conditions, or to produce the same average power as shown for each phase, or to stay within the envelope of the two traces. For future work by Avco this specification is not necessary; however, it seems that the general goal is to produce the same average power as shown for each phase. (The power requirements for the sustain phase have also been changed from 1.058 to 1.148 and from 1.720 to 1.866 GHP.)

Figure 1. Schematic diagram of hot-gas-supply system.



(where w_2 is the gas-flow rate, lb/s; γ the ratio of specific heats of the gas; T_2 the gas temperature at the nozzle, R; $\bar{m}_2$ the gas molecular weight; p_e the turbine exhaust pressure (one standard atmosphere), and p_2 the gas pressure at the nozzle) is directly proportional to the gas temperature, the maximum allowable gas temperature at the nozzle is 1800 F.

As originally specified, Avco's responsibility for the analysis extended from the gas-generator exit, at which Avco was to specify the gas-flow rate, through the nozzle, at which point the gas horsepower was to satisfy the requirements of Figure 2.

3.0 GAS PROPERTIES

Two propellants, specified by Don Keathley of Raymond Engineering, were considered. Their compositions are given in Table 1; minor constituents (<1%) were ignored.

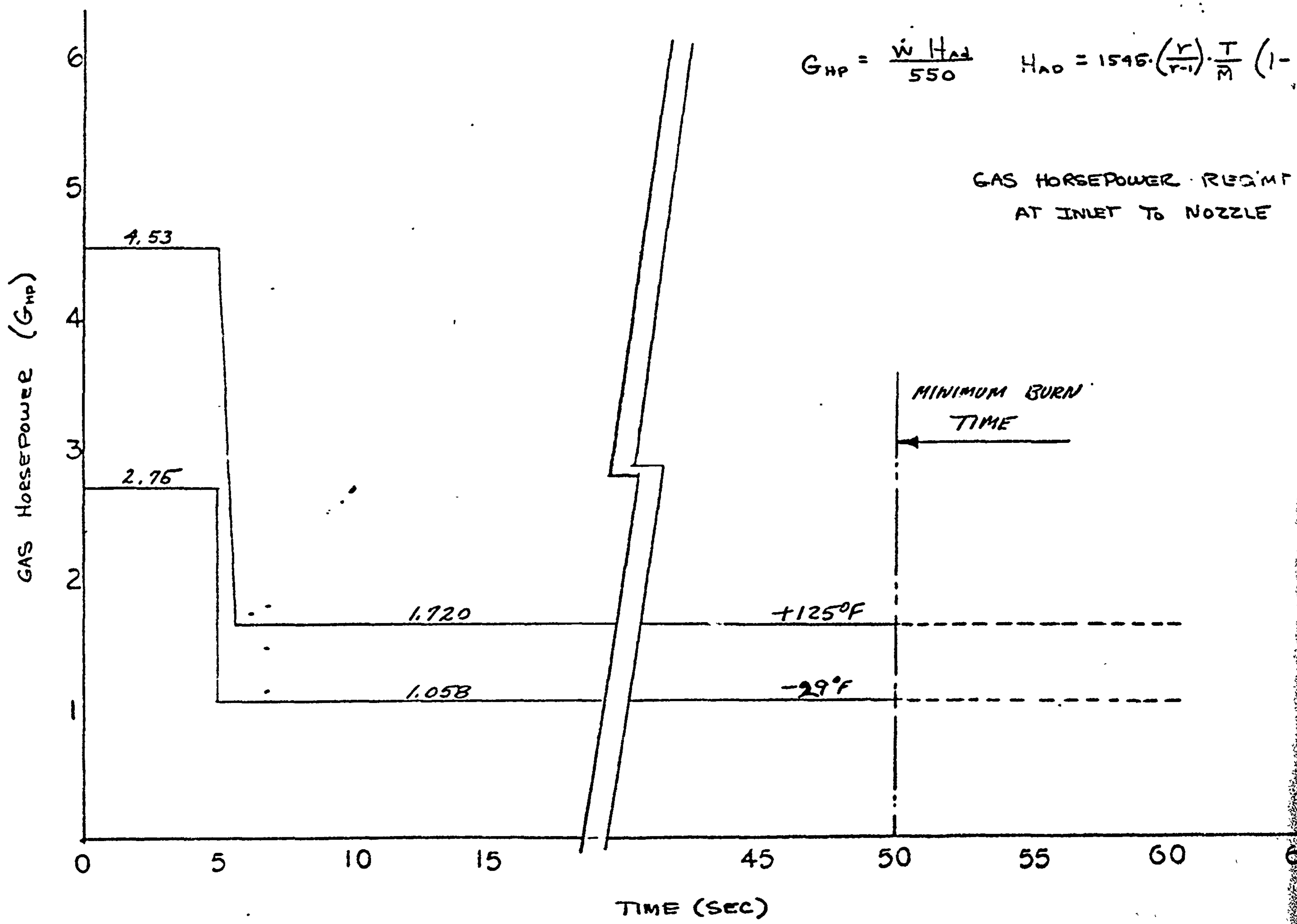
TABLE 1. PROPELLANT COMPOSITIONS (MOLE FRACTIONS)

	TAL 431 ($\bar{m}$ = 19.1)	OMAX 541 ($\bar{m}$ = 20.0)
Hydrogen, H_2	0.271	0.288
Water, H_2O	0.299	0.109
Nitrogen, N_2	0.202	0.254
Carbon Monoxide, CO	0.156	0.257
Carbon Dioxide, CO_2	0.072	0.060
Methane, CH_4	0.000	0.032
	1.000	1.000

(The ratio of specific heats for both propellants is given as 1.27.)

The gas properties required for the thermal analysis are the viscosity μ, specific heat (at constant pressure) c_p, and Prandtl number N_{Pr}. Although the thermal conductivity k does not appear explicitly in the heat-transfer formulations used,

Figure 2. Gas horsepower requirements.



it is required to determine the value of the Prandtl number ($N_{Pr} = c_p\, g_c\, \mu / k$) unless that quantity is directly available. The specific heat is of course implied by the given values of $\overline{m}$ and γ: $c_p = \gamma \overline{R}/(\gamma-1)\,\overline{m}$, where $\overline{R}$ is the universal gas constant 1.986 B/lbmol·R.

TAL 431: $c_p = 0.489$ B/lb·F

OMAX 541: $c_p = 0.467$ B/lb·F

The values of viscosity, thermal conductivity, and Prandtl number may be significantly affected by the relatively large amount of hydrogen in the mixtures. Simple weighted averaging does not apply to transport properties of such gas mixtures. The viscosities of the mixtures were calculated from the expression[1]

$$\mu = \sum_{i=1}^{\nu} \frac{\mu_i}{1 + \sum\limits_{\substack{j=1 \\ j \neq i}}^{\nu} \Phi_{ij} \dfrac{\overline{x}_j}{\overline{x}_i}} ,$$

where

$$\Phi_{ij} = \frac{\left[1 + \left(\dfrac{\mu_i}{\mu_j}\right)^{1/2} \left(\dfrac{\overline{m}_j}{\overline{m}_i}\right)^{1/4}\right]^2}{2\sqrt{2}\left[1 + \left(\overline{m}_i/\overline{m}_j\right)\right]^{1/2}}$$

---

[1] W. M. Rohsenow and J. P. Hartnett, "Handbook of Heat Transfer," McGraw-Hill, 1973.

and ν is the number of components of the mixture. At a temperature of 1500 F, the resulting values of viscosity are

$$\text{TAL 431:} \quad g_c \mu = 0.101 \text{ lb/h·ft}$$

$$\text{OMAX 541:} \quad g_c \mu = 0.00995 \text{ lb/h·ft,}$$

both of which are very close to the viscosity of water vapor, nitrogen, carbon monoxide, or carbon dioxide (or air) at the same temperature, ~0.102 lb/h·ft. The value $g_c \mu = 0.100$ lb/h·ft was used in the analysis for both propellants.

The thermal conductivities of the mixtures are expected to be more strongly affected by the presence of the hydrogen. In order to calculate the thermal conductivity of such a gas mixture by the methods of Reference 1, the thermal conductivities of the components must be split into monatomic and diffusional contributions, and separate expressions (of which the simpler one is similar to the one used for viscosity) used to calculate the two contributions to the mixture thermal conductivity. There was not enough time allotted to this task to perform these calculations.

Instead of determining the thermal conductivity, a value for the Prandtl number was obtained directly from a chart for mixtures of hydrogen and hydrocarbons[(2)]: $N_{Pr} = 0.6$. The use of this value, which is not for the specific gas mixtures and temperature considered, introduces an uncertainty in the gas heat-transfer coefficients used in the analysis. However, even if the true value of the mixture Prandtl number is as low as 0.4, the resulting error in the heat-transfer coefficient is only 25%, which is comparable with typical uncertainties in heat-transfer correlations.

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[2] Personal communication, M. Ziering.

4.0 GAS HEAT-TRANSFER COEFFICIENTS

The gas-to-wall heat-transfer coefficients were calculated from the expression

$$h = N_{St}\, G\, c_p,$$

where N_{St} is the Stanton number and G the mass flow rate per unit area. The value of the Stanton number was obtained from the Kays and London[3] correlation (Figure 7-1, p. 123) of $N_{St}\, N_{Pr}^{2/3}\, (T_w/T_m)^{-n}$ vs N_{Re}, where T_w is the wall temperature, T_m the mean gas temperature, and $N_{Re} = GD_i/g_c\mu$ the Reynolds number (D_i is the flow-passage diameter). The recommended value of the exponent n for cooling of the gas is zero for all Reynolds numbers outside the laminar-turbulent transition region ($2 \leq 10^3\, N_{Re} \leq 10$). Unfortunately, the gas-flow rates of interest in the 0.21-in.-ID tube lie mostly within the transition region (w = 0.0038 lb/s corresponds to N_{Re} = 10 000) where the value of n is not given and the correlation is in general more uncertain. A value of n = 0 was also assumed for this region. The correlation of $N_{St}\, N_{Pr}^{2/3}$ vs N_{Re} also depends on the L/D ratio of the tube. Tubes 10- and 20-in. long have L/D ratios of 47.6 and 95.2; the curves for L/D = 50 and 100 were used. The curves for T constant, rather than ΔT constant, were used.

The use of correlations for finite L/D ratios automatically includes the effect of the enhanced entrance-region heat transfer in the mean value of h over the tube length. For the valve flow passage, which is only 2.5 L/D, a special expression due to Latzko[4] for entrance-region heat transfer was used:

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[3] W. M. Kays and A. L. London, "Compact Heat Exchangers," 2nd ed., McGraw-Hill, 1964.

[4] W. H. McAdams, "Heat Transmission," 3rd ed, McGraw Hill, 1954.

$$h_x/h_\infty = 0.866\ N_{Re}^{0.055}\ (D_i/x)^{0.22},$$

where h_x is the heat-transfer coefficient at distance x from the inlet, and h_∞ the heat-transfer coefficient for an infinitely long tube. The mean heat-transfer coefficient in the valve passage was determined by integration to be

$$\bar{h}_v = (0.866/0.78)\ (D_i/D_v)^{0.22}\ N_{Re}^{0.055}\ h_\infty,$$

where the passage length was taken to be the valve-ball diameter D_v.

Application of this expression when the Reynolds number $N_{Re} = G\ D_i/g_c\mu$ falls in the transition region presents a problem, since the curves for Stanton number in an infinitely long tube are not shown for $3 < 10^3\ N_{Re} < 10$. In this region, $h_{L/D=100}$ was used instead of h_∞. The values for gas-to-valve heat-transfer coefficient and the resulting values for gas-temperature drop in the valve are thus uncertain for the lower flow rates ($w < 0.038$ lb/s).

5.0 ANALYSIS OF THERMAL TRANSIENT

5.1 SUPPLY TUBE

In order to understand the transient behavior of the gas-flow system, some simplified preliminary analyses were performed. First, the thermal time constant τ of the tube wall was determined: $\tau = \rho c \delta/h$, where ρ is the tube-wall density, c its specific heat, and δ its thickness*. The thermal time constant is the

---

*Since the tube wall is not thin relative to its diameter, its thickness δ was replaced by $\delta' = (D_o^2-D_i^2)/4\ D_i$; i.e., the ratio of cross-section to perimeter. This effective thickness is about 10% greater than the actual thickness.

time required for the difference between the wall and gas temperatures to become the fraction 1/e of the initial difference, for constant gas temperature and heat-transfer coefficient. The magnitude of the time constant depends on the gas-flow rate:

Tube-wall thermal mass per unit area

$$\rho c \delta' = 0.33 \text{ lb/in.}^3 \times 0.09 \text{ B/lb·F} \times 0.0219 \text{ in.} \times 144 \text{ in.}^2/\text{ft}^2 = 0.0937 \text{ B/ft}^2\text{·F}$$

1. Boost phase, w = 0.0049 lb/s (flow required to obtain specified GHP at T_a = 125 F, T_g = 1800 F with OMAX 541):

$$h_{L/D=100} = 0.0435 \text{ B/s·ft}^2\text{·F}$$

$$\tau = 0.0937/0.0435 = 2.15 \text{ s.}$$

2. Sustain phase, w = 0.0014 lb/s (flow required to obtain specified GHP at T_a = -29 F, T_g = 1800 F with OMAX 541):

$$h_{L/D=100} = 0.0080 \text{ B/s·ft}^2\text{·F}$$

$$\tau = 0.0937/0.0080 = 11.7 \text{ s.}$$

The first value of τ shows clearly that thermal transients will be significant in the 5-second boost phase. The second value shows that at least by the end of the sustain phase the thermal transient will be over (in fact, the results to be discussed below show that the boost phase leaves the system nearly in thermal equilibrium at the beginning of the sustain phase).

Consider the beginning of the boost phase. The velocity of hot gas in the tube is about 20 ft/s (because of the choked-flow nozzle downstream of the supply tube, the pressure is proportional to the flow rate, and therefore the gas velocity depends primarily on the gas temperature). The transit time of the hot gas is about 0.05 s in the 10-in. tube and 0.10 s in the 20-in. tube.

Since the time constant of the tube wall is about 2 seconds, the initial gas flow in the boost phase will pass through a tube which is still completely cold. The tube therefore acts as a heat exchanger which cools the gas. The amount of cooling depends on the number of transfer units of the exchanger for the given gas flow: $N_{tu} = A_x\ h/w\ c_p = \pi D_i\ L\ h/w\ c_p$, where L is the tube length. For a flow rate of 0.0049 lb/s of the TAL 431 propellant* in a 20-in.-long supply tube (h = 0.0455 $B/s \cdot ft^2 \cdot F$)

$$N_{tu} = \frac{\pi \times 0.21\ \text{in.} \times 20\ \text{in.} \times 0.0455\ B/s \cdot ft^2 \cdot F}{144\ \text{in}^2/ft^2 \times 0.0049\ lb/s \times 0.489\ B/lb \cdot F} = 1.74\ ;$$

the corresponding heat-exchanger effectiveness is

$$\varepsilon \equiv \frac{T_{gi} - T_g}{T_{gi} - T_w} = 1 - e^{-N_{tu}} = 0.824\ ,$$

where T_{gi} is the gas inlet temperature. Even without considering the gas-temperature drop in the valve, the initial gas outlet temperature for the -29 F ambient condition would be T_g = 2100-0.824 (2100 + 29) = 346 F. This result cannot be changed by insulating the tube; the heat loss is not from the outside of the tube but is directly to the tube itself acting as a heat sink. The only way to achieve a significant increase in the initial gas outlet temperature (other than preheating the supply tube) would be to increase the gas-flow rate drastically (an order of magnitude or more) in order to increase the heat-transfer coefficient enough to make the thermal time constant of the tube wall comparable with the gas-transit time.

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*Although the example gas-flow rates are based on preliminary calculations by Garrett for a propellant having the same molecular weight as OMAX 541, TAL 431 has since been selected by Raymond Eng. This propellant has about 5% higher heat-transfer coefficient than OMAX 541, and a 2100-F burning temperature vs 1925-F for OMAX 541.

The complete transient solution for an insulated tube with constant gas inlet temperature is available in tabular form in Reference 3 (Chapter 3, Case 18). This solution is valid for the hot-gas flow system until the supply tube becomes hot enough that radiation from the outside surface becomes significant. For the gas-flow case above, where the initial gas outlet temperature is 346 F, the outlet temperatures rise to 920 and 1520 F after 2 and 5 seconds, respectively. These results illustrate the highly transient nature of the boost phase.

Consider, on the other hand, the end of the sustain phase. At this time the thermal transient is over, and any part of the tube wall is in thermal equilibrium between the heat convected to it by the gas inside and the heat radiated to the surroundings outside. The energy balance for the gas is

$$-wc_p \frac{dT_g}{dx} = \pi D_i h (T_g - T_w)$$

and that for the tube wall is

$$\pi D_i h (T_g - T_w) = \pi D_o \epsilon \sigma (T_w^4 - T_a^4) ,$$

where ϵ is the thermal emissivity of the tube outer surface and σ is the Stefan-Boltzmann constant; these equations can be combined to yield a single differential equation for the tube-wall temperature as a function of distance along the tube:

$$\left(\frac{4 D_o \epsilon \sigma T_w^3}{D_i h} + 1 \right) \frac{dT_w}{dx} + \frac{\pi D_o \epsilon \sigma}{wc_p} (T_w^4 - T_a^4) = 0 .$$

APPENDIX G

GAS GENERATOR COMPATIBILITY

TEST REPORT

COMPATIBILITY TEST REPORT

PERSHING II
GAS GENERATOR

Contract No. 296063

October 30, 1978

Raymond Engineering Inc.
217 Smith Street
Middletown, CT 06457

GAS GENERATOR COMPATIBILITY
TEST REPORT

Requirements

The requirements for the Pershing II, Phase I, Warm Gas Generator are listed in Table I. This interface specification defines the gas generator characteristics necessary to operate the Pershing II, Phase I Turboalternator and provides a basis for the preliminary operating model design and test effort for both the gas generator and turboalternator.

Gas Generator Development

To provide background data for the gas generator compatibility tests, the following is a discussion of the gas generator performance at the end of Phase I development program. A preliminary operating model of the warm gas generator was developed which demonstrated feasibility and indicated the stated requirements could be attained. At this point, REI indicated that the POM gas generator would require changes to tailor the design to produce the required gas horsepower profile. Since the actual gas horsepower required to operate the turboalternator might further change the design requirements, a compatibility test was necessary to define the design tailoring for the gas generator.

Background test data for the Phase I gas generator development is provided in Figures 1 through 6. These gas horsepower curves show the REI gas generator test performance as compared to the required limits indicated as dashed lines. The low gas horsepower

TABLE 1

SOLID PROPELLANT CHARACTERISTICS OF HOT GAS SUPPLY FOR PERSHING II TURBOALTERNATOR

SUSTAIN		BOOST	
P_{min}	= 420 psia	P_{min}	= 900 psia
P_{max}	= 634 psia	P_{max}	= 1396 psia
GHP_{min}	= 1.148	GHP_{min}	= 2.75
GHP_{max}	= 1.866	GHP_{max}	= 4.53
T_{max}	= 1800°F	T_{max}	= 1800°F
W_{min} (REF)	= .0015 lb/sec	W_{min} (REF)	= .0031 lb/sec
W_{max} (REF)	= .0022 lb/sec	W_{max} (REF)	= .0049 lb/sec

Generator gas should be filtered and the maximum permissible particle is .001 inch in diameter,

Ambient Temperature MAX = +125°F

MIN = -29°F

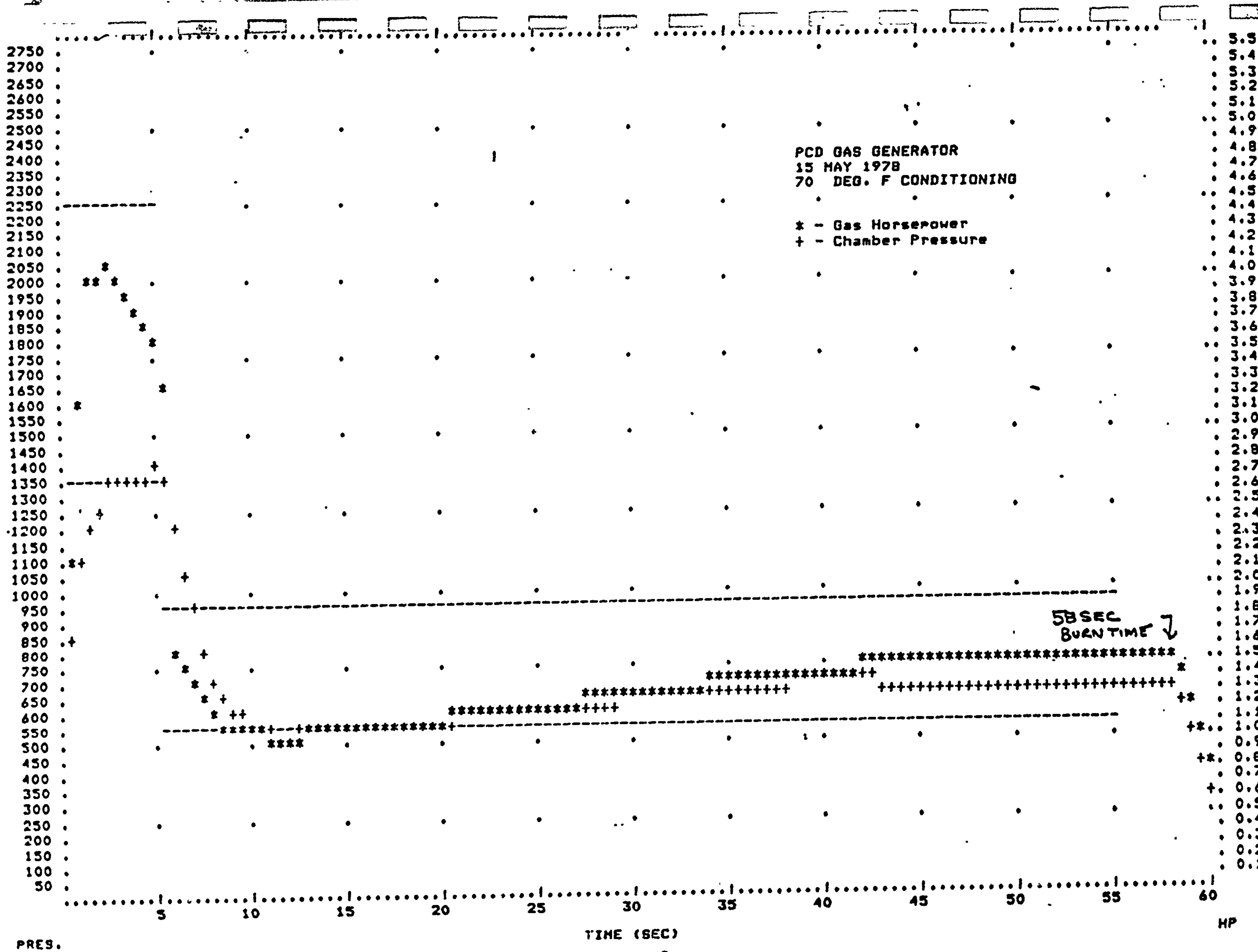
NOTES:

1) The total burn time shall be 55 seconds and the boost phase shall not exceed 5 seconds.

2) The transition from boost to sustain phase shall be smooth.

3) Final approval of propellant requires review for compatibility with the turboalternator and other components within the system.

4) Nozzle area (nom) = .000409 in²



PCD GAS GENERATOR
15 MAY 1978
70 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
58SEC BURNTIME
PRES.
TIME (SEC)
HP

FIGURE 1

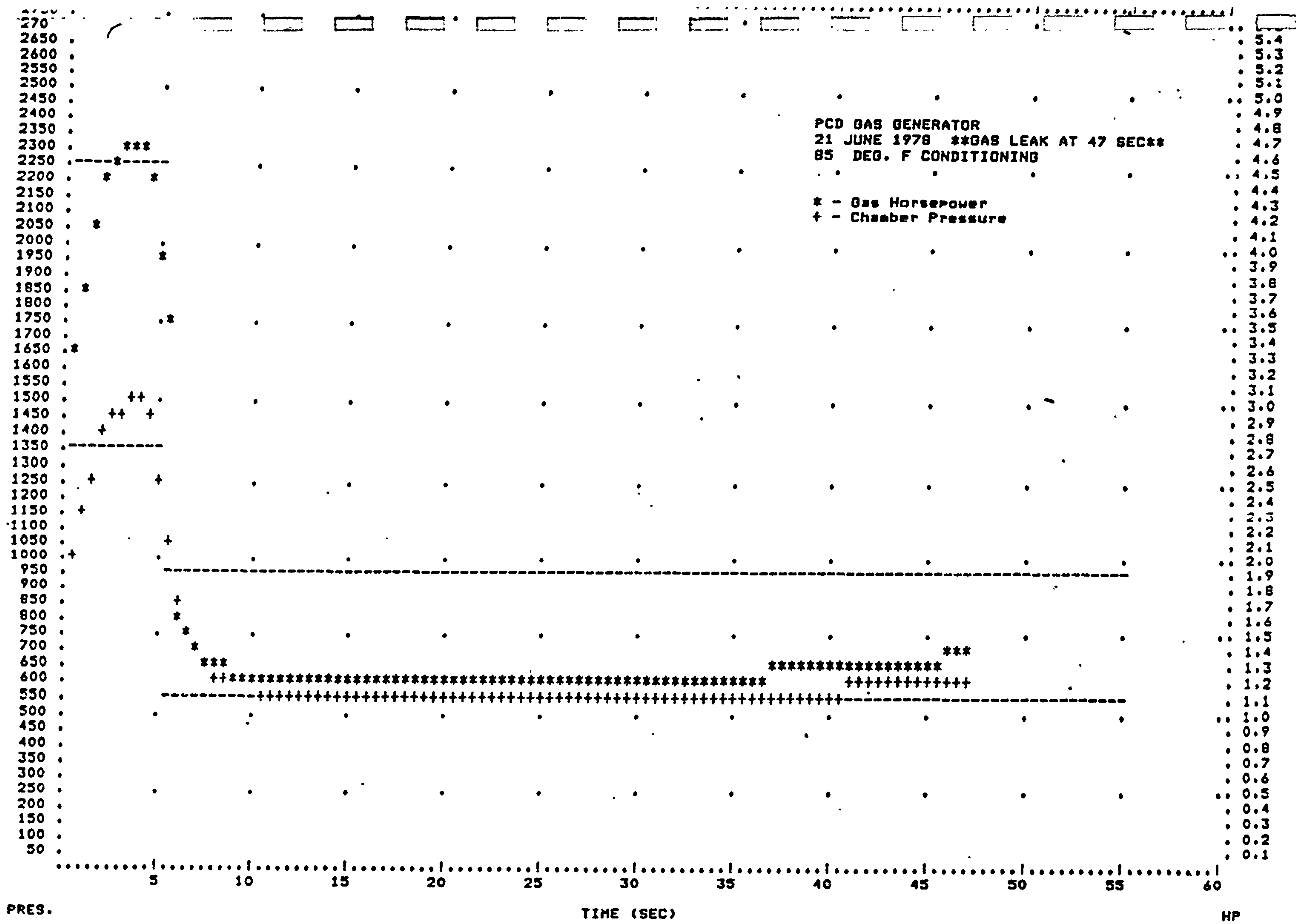

PCD GAS GENERATOR
21 JUNE 1978 **GAS LEAK AT 47 SEC**
85 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 2

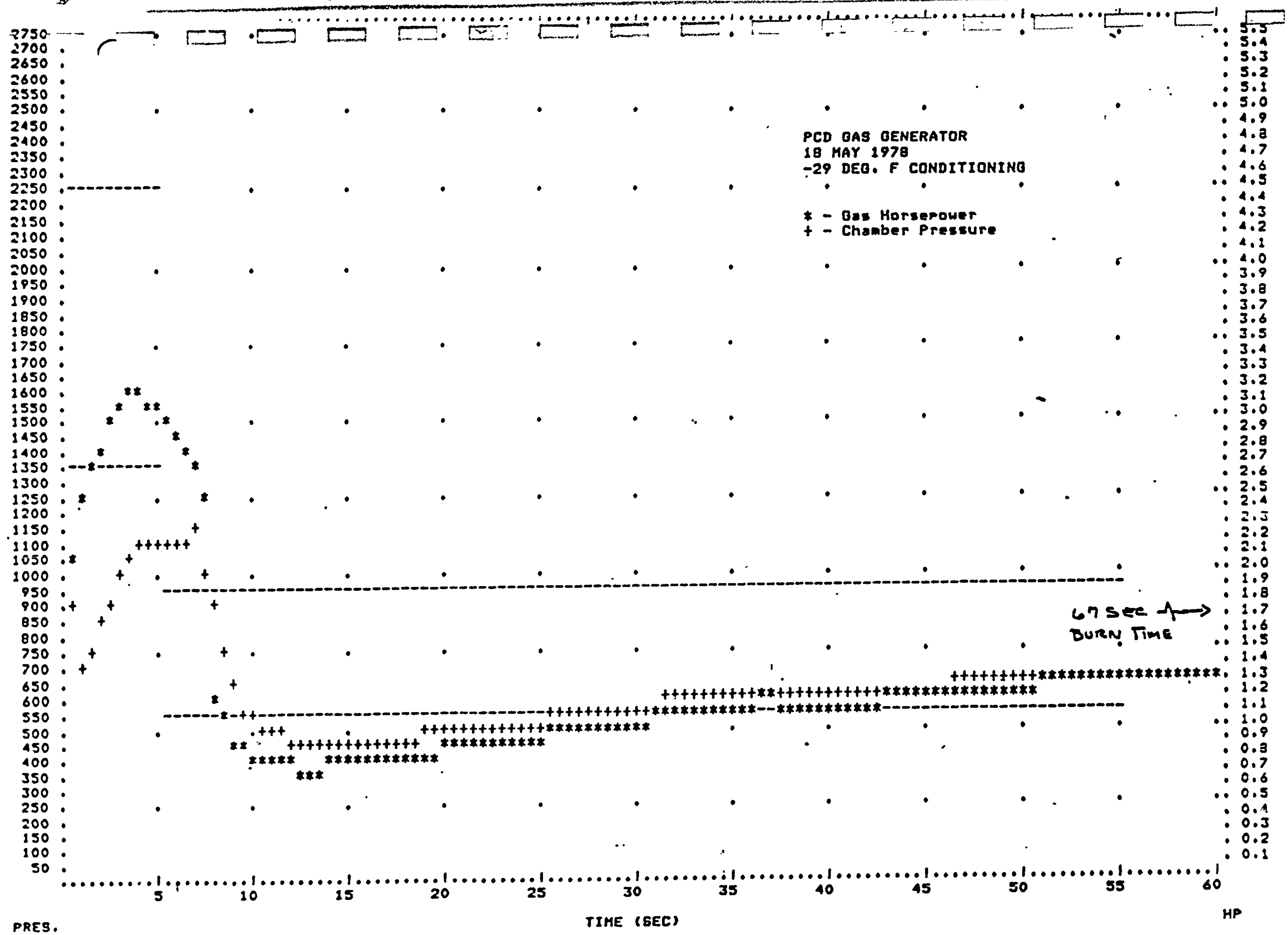

PCD GAS GENERATOR
18 MAY 1978
-29 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
67 SEC
BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 3

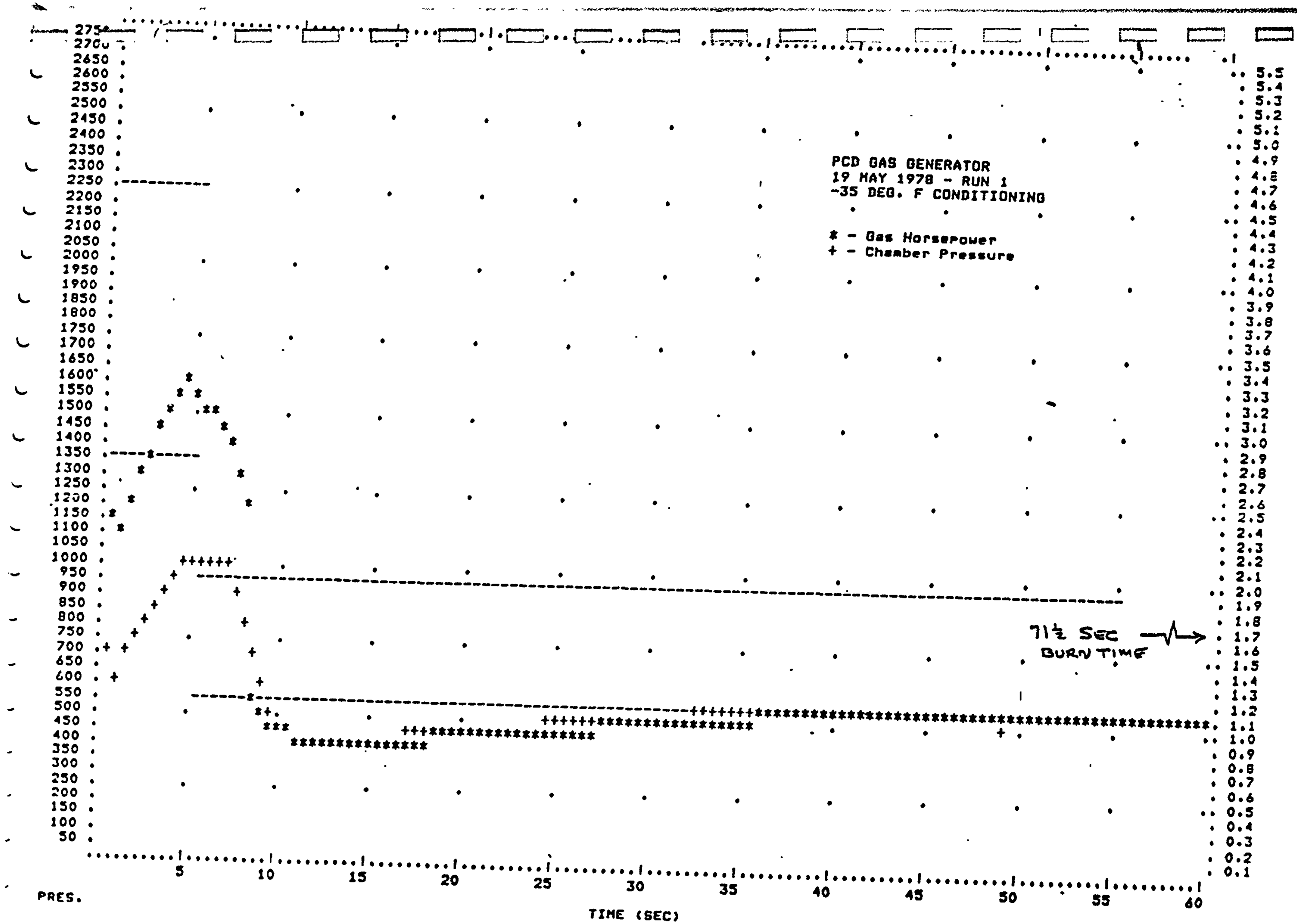

PCD GAS GENERATOR
19 MAY 1978 - RUN 1
-35 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
7½ SEC
BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 4

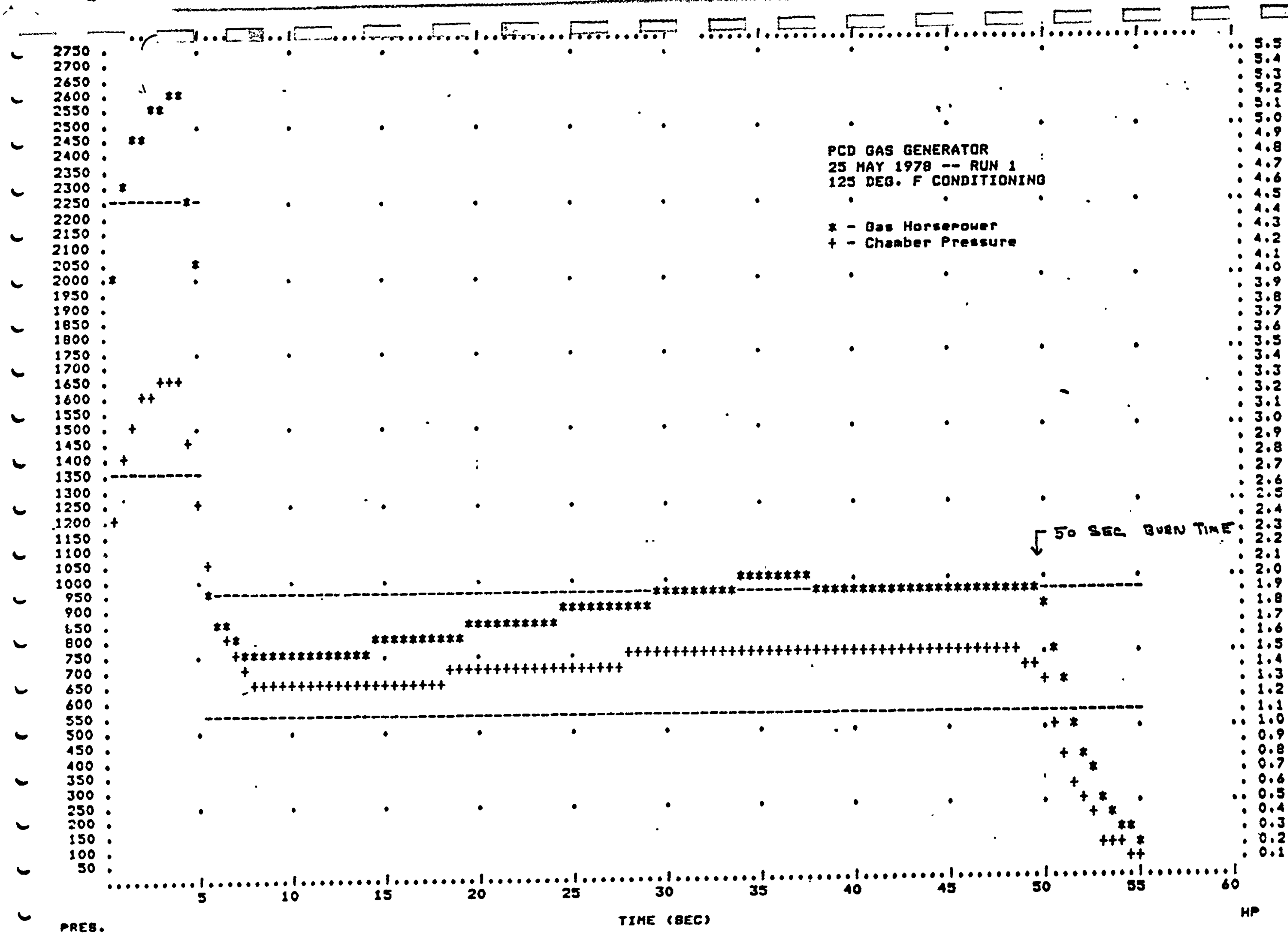

PCD GAS GENERATOR
25 MAY 1978 -- RUN 1
125 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
50 SEC BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 5

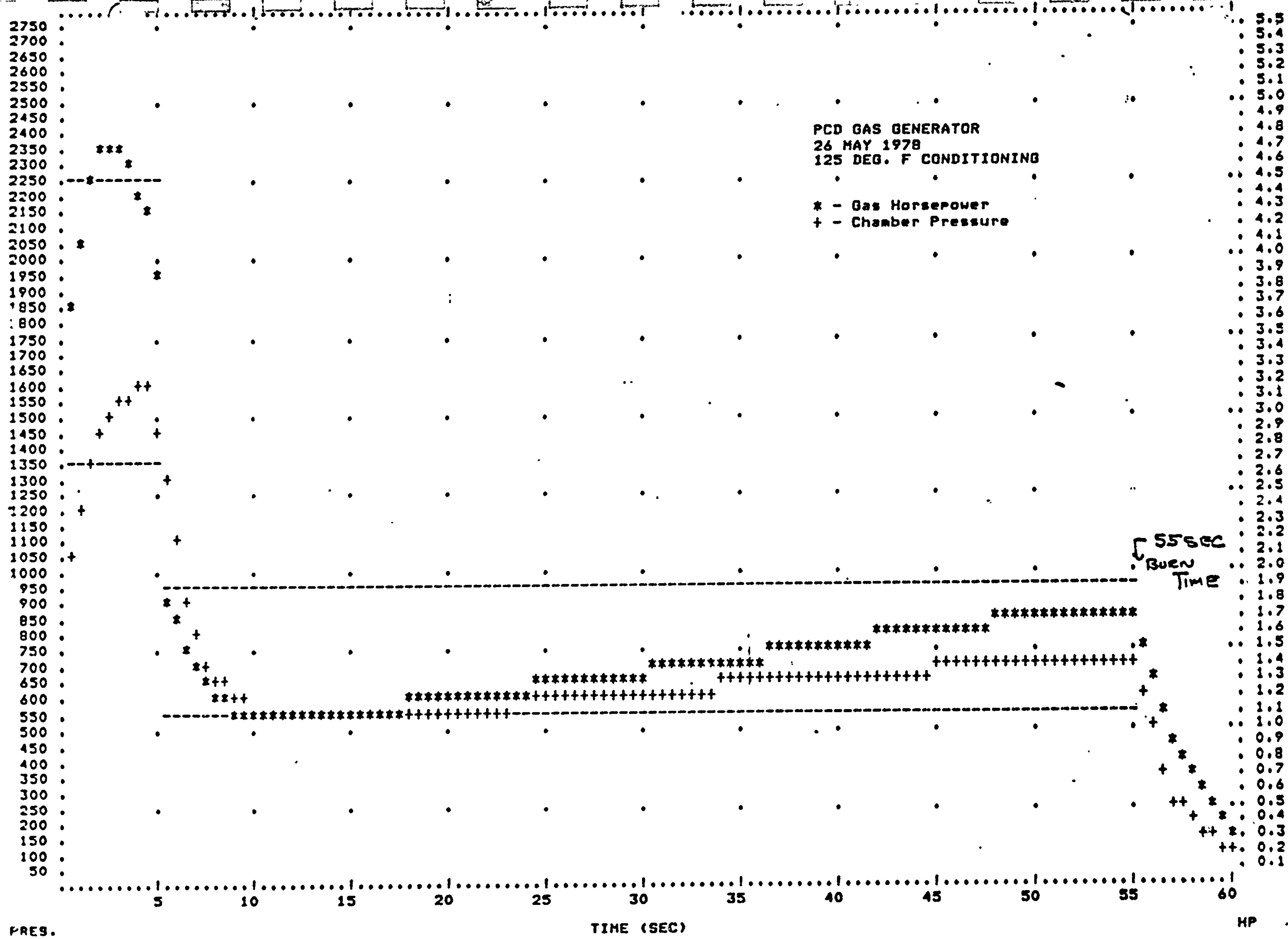

PCD GAS GENERATOR
26 MAY 1978
125 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
55 SEC BURN TIME
PRES.
TIME (SEC)
HP

FIGURE 6

in the beginning of the sustain phase during cold tests, the high gas horsepower in the boost during hot tests and the gradual increase of gas horsepower during the sustain phase are all correctable problems by tailoring the POM design.

Description of Compatibility Test Units

The test units included a POM gas generator and control valve assembled together with the Garrett instrumented transfer tube attached to the control valve output plate and an instrument port on the chamber centerline of the gas generator.

Configuration of the POM design for the gas generator and control valve is defined by the attached assembly drawing (P/N 2379-100 and 2379-200). This design configuration used for the Garrett compatibility tests is identical to the units prepared for the REI development tests at the end of Phase I. A modified valve shaft was used during these tests in lieu of a redesigned valve shaft required in Phase II to withstand the valve torque requirement.

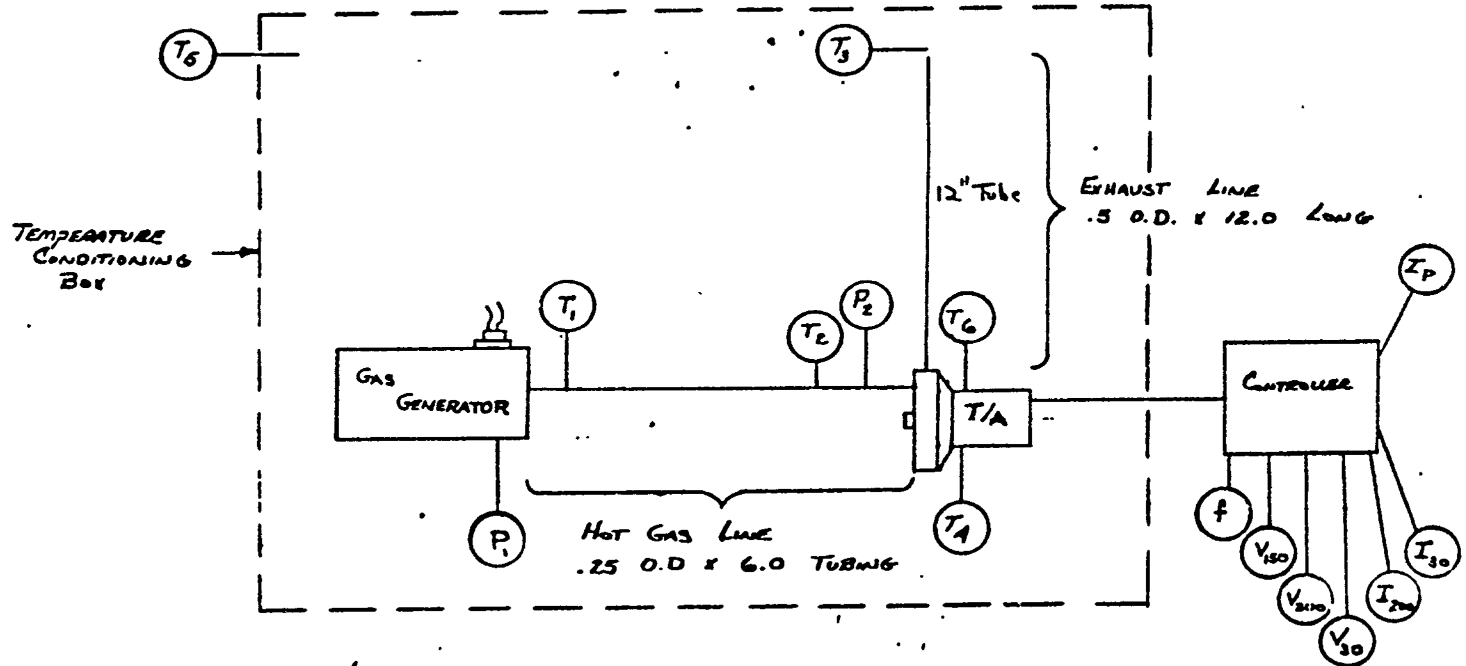
Solid propellant from the Phase I test lot was used in the four (4) gas generators tested with the turboalternator. The second lot of solid propellant purchased was used for one calibration test with gas generator only, prior to the four (4) compatibility tests.

The instrumentation schematic for the four (4) gas generator/ turboalternator compatibility tests is shown in Table II.

PART NO.. MODEL NO..

PREPARED BY ______ CHECKED BY ______

Gas Generator / Turboalternator Compatibility Test Schematic



Instrumentation List

T_1	Gas Generator Outlet	2000 °F max
T_2	Turboalternator Inlet	1500 °F max
T_3	Turboalternator Exhaust	1000 °F max
T_4	Turboalternator	600 °F max
T_5	Conditioning Box	-29 -To +125 °F
T_6	Bearing Temp	500 °F max
P_1	Gas Generator Outlet	1600 PSIG max
P_2	Turboalternator Inlet	1500 PSIG max
f	Frequency	7500 Hz max
V_{150}	Voltage	160 V max
V_{200}	Voltage	200 V max
V_{30}	Voltage	30 V max
I_{200}	Current	.70 mA max
I_{30}	Current	5 Amp max

Oscillograph trace will also include:

- A one second timer
- Squib current indicator

TABLE II

Compatibility Test Plan

The five (5) tests at Garrett followed the sequence listed below:

Test No.	Date	GG Propellant	Temp Cond.	Test Description
1	2 Oct	2nd Lot T-433	Ambient	Calibration GG Only
2	2 Oct	1st Lot T-433	Ambient	Compatibility GG/TA
3	3 Oct	1st Lot T-433	Hot(125°F)	Compatibility GG/TA
4	4 Oct	1st Lot T-433	Cold(-29°F)	Compatibility GG/TA
5	5 Oct	1st Lot T-433	Cold(-29°F)	Compatibility GG/TA

Compatibility Test Data

The gas generator test data for the five (5) compatibility tests is summarized below:

			BOOST				SUSTAIN			
Run	Date	Test Desc.	Peak Press	Press Saddle	Press End	Burn Time	Press Saddle	Press End	Final Time	Final Temp
			(psig)	(psig)	(psig)	(Sec)	(psig)	(psig)	(Sec)	(°F)
1	2 Oct	G.G. Amb. Temp	1480	1260	1260	4.7	545	790	54.3	1104
2	2 Oct	G.G./ T.A. Amp Temp	1685	1275	1500	4.3	615	610	52.0	1059
3	3 Oct	G.G./ T.A. +125°F	1740	1305	1770	5.0	640	750	48.2	1072
4	4 Oct	G.G./ T.A. -29°F	700	400	890	9.8	385	485	79.0	806
5	5 Oct	G.G./ T.A. -29°F	880	445	875	8.4	420	500	77.5	722

The test data for each run was reduced to approximately thirty (30) data points for pressure and temperature to calculate the gas horsepower. Figures 7 through 12 show the gas generator performance in gas horsepower and chamber pressure for the five (5) compatibility tests. The required levels of gas horsepower are shown in these charts by dashed lines.

Run 1 - G.G. Cal.

Data shows G.G. #1 had a high temperature and gas horsepower during boost and a gradually increasing pressure and gas horsepower during sustain. Sustain pressure was high after 22 seconds.

Run 2 - G.G./T.A. Amb.

During this run the G.G. temperature, pressure and gas horsepower were high during boost. Sustain pressures were unusually high and stepped down 100 psig at 40 seconds, then gradually decreased to a more normal level.

Run 3 - G.G./T.A. Hot

Boost pressure, temperature and gas horsepower were high. The sustain pressures were also high and stepped down 100 psig after 25 seconds, then gradually increased for the remainder of the run.

Run 4 - G.G./T.A. Cold

The shape of the boost profile had a marked difference ~~than~~ any previous test. Boost pressure, temperature and gas horsepower were low with an extended saddle between ignition and burn. The boost time was unusually ~~low~~. The sustain temperature and gas horsepower were low throughout the run.

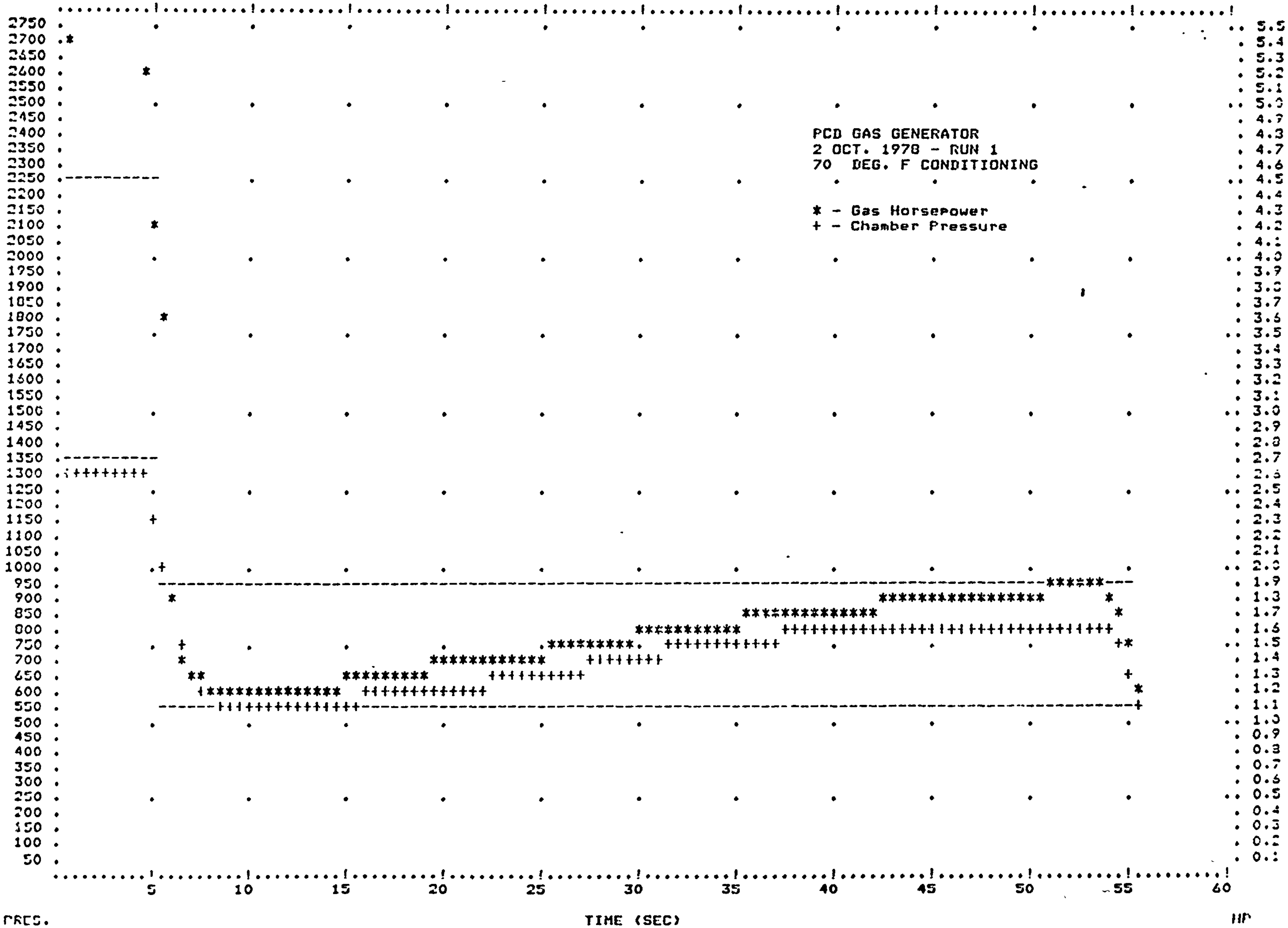

PCD GAS GENERATOR
2 OCT. 1978 - RUN 1
70 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 7

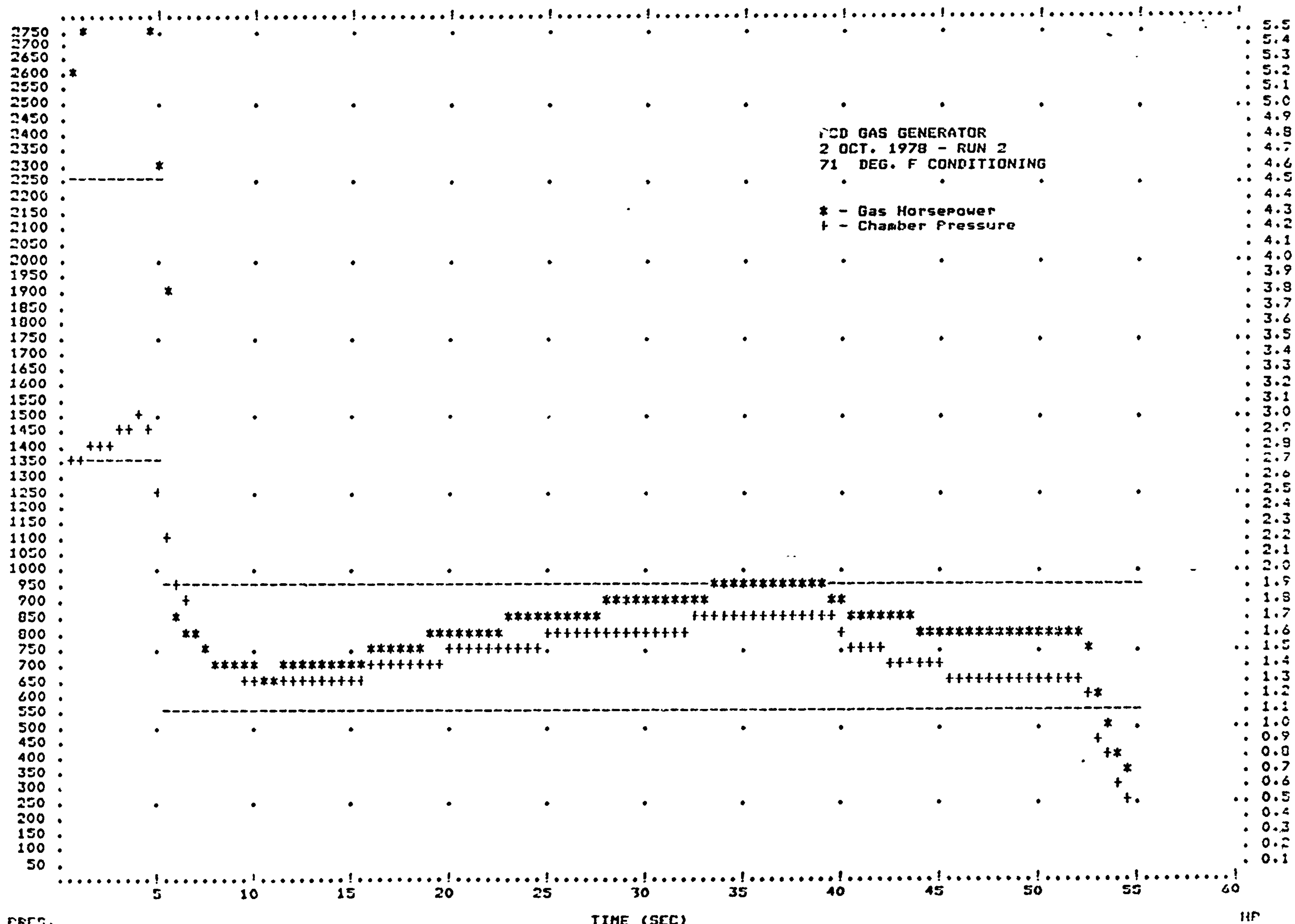

FCD GAS GENERATOR
2 OCT. 1978 - RUN 2
71 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 8

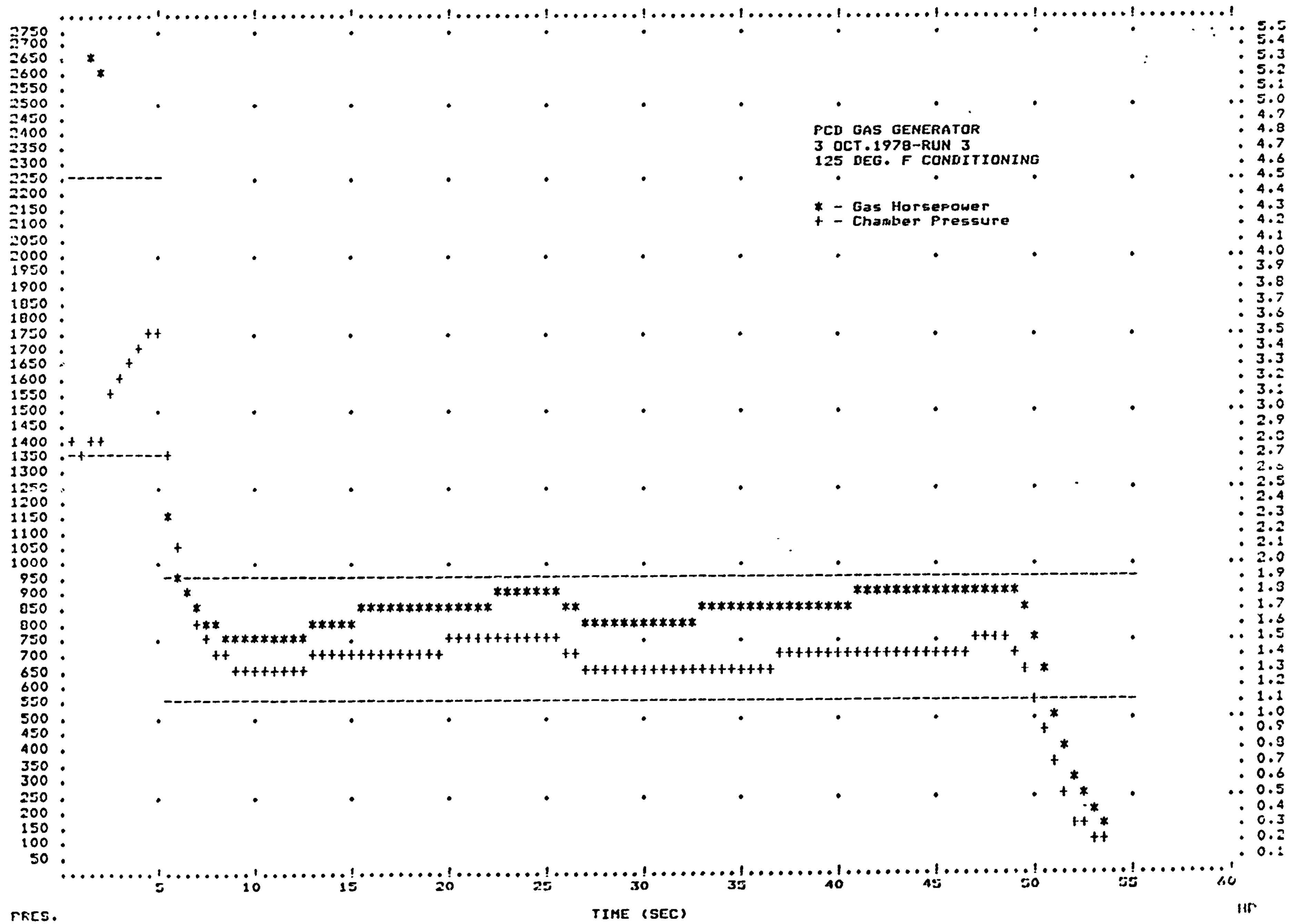
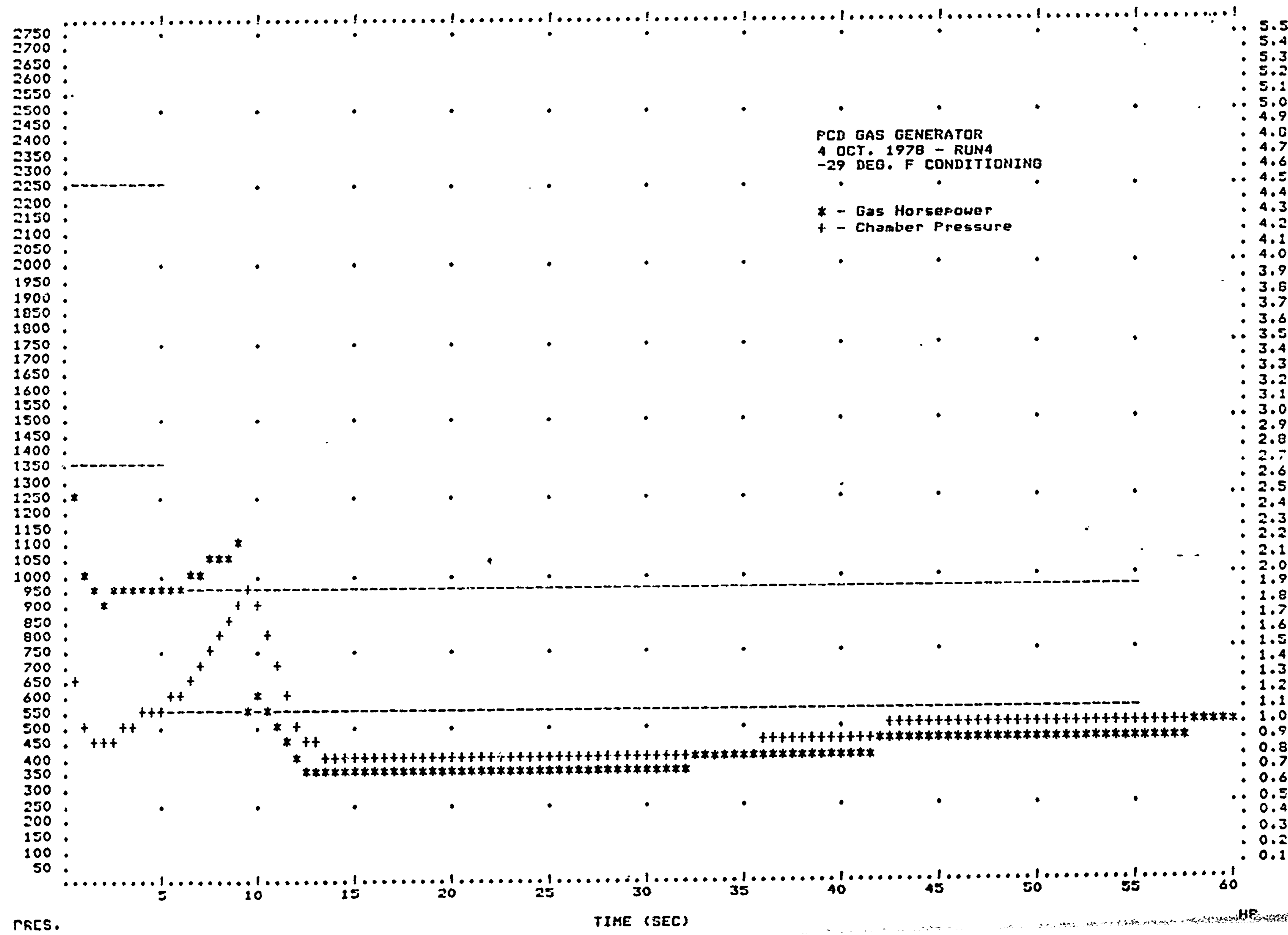

PCD GAS GENERATOR
3 OCT.1978-RUN 3
125 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 9



PCD GAS GENERATOR
4 OCT. 1978 - RUN4
-29 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

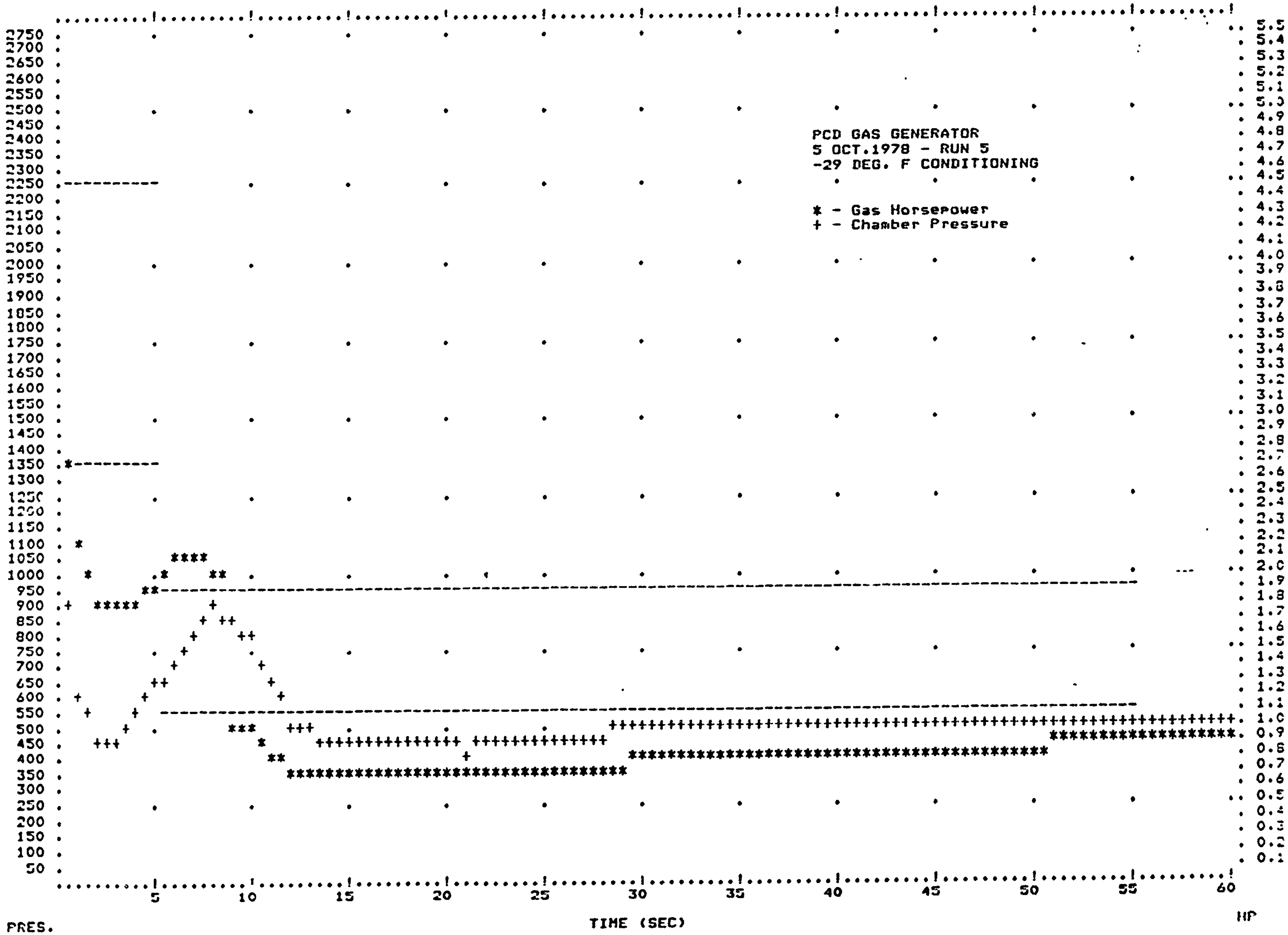

PCD GAS GENERATOR
5 OCT.1978 - RUN 5
-29 DEG. F CONDITIONING
* - Gas Horsepower
+ - Chamber Pressure
PRES.
TIME (SEC)
HP

FIGURE 11

Run 5 - G.G./T.A. Cold

G.G. performance was essentially the same as Run 4.

Conclusions

In conclusion the compatibility tests successfully demonstrated the POM gas generator and turboalternators are at a design level to allow system integration. Some adjustments will be required for both units to fully meet the performance requirements under all environmental conditions.

APPENDIX H

GARRET COLD TEMPERATURE TEST ANOMALY ROOT CAUSE ANALYSIS

GARRETT COLD TEST ANOMALY

GAS GENERATOR - ROOT CAUSE ANALYSIS

OBJECTIVES:

- List all possible causes from test data analysis
- Define differences between Garrett & REI cold tests
- Analysis possible causes and determine root causes
- Develop test plan to verify root causes
  - Duplicate problem to induce failure
  - Use Garrett nozzle design
  - FLOW NOZZLE BEFORE & AFTER GG TESTS
- Define design modification to resolve root causes
  - Incorporate design mod's. for profile improvements

GAS GENERATOR COMPAT. TESTS

LIST OF POSSIBLE CAUSES

RUN 1	Results	Cause	Resolution
G.G. Only	High Boost P,T & GHP	Design	Adjust cross section
Amb.	Gradual > sustain P	Design	Tapper grains
	· Sustain P high @ 22 sec	Nozzle Blockage	Filtering Efficiency
RUN 2			
G.G./T.A.	High Boost P,T & GHP	"	"
Amb.	High Sustain P	Nozzle Blockage	Improve filter ?
	100 psig step down at 39 sec & decrease to more normal P	Leakage	Not supported by Hdw
		Nozzle Cleared	Improve filter
RUN 3			
G.G./T.A.	High Boost P,T & GHP	"	"
Hot	High Sustain P	Nozzle Blockage	"
	100 psig stepdown at 2? sec	Leakage	"
		Nozzle Clear	"
RUN 4			
G.G./T.A.	Low Boost P,T & GHP	Marginal Ignition	Adjust Ign Mix
Cold	Long Boost Time	Conditioning - Ice buildup, Abnormal Heat Loss	Improved Test Method
	Low Sustain T & GHP	Leakage	Not Supported by Hdw
	White particles in Turbo	Water Absorption	IMPROVE SEALING Closure Disc
	Carbon build up in Turbo buckets		
RUN 5	"	"	"
G.G./T.A.	"	"	"
Cold	"	"	"
	"	"	"

NOTE:
- Add Process of instrumentation — GG Seal @ Kin
- List closure disc rupture P
- How closure rupture ? — new traps / sharp edge
- P tap opened @ Garrett to install instrumentation
-

Test Method Differences - GAM vs REI Cold Tests

* Nozzle — GAM line dia. step down to throat (venturi) - REI line dia opens up before (slow

* Condition Method — CO_2/controller - styrofoam box - Hot, Humid day ~95

* Transfer Tube Lg. - GAM 5" Lg vs REI 20" Lg.

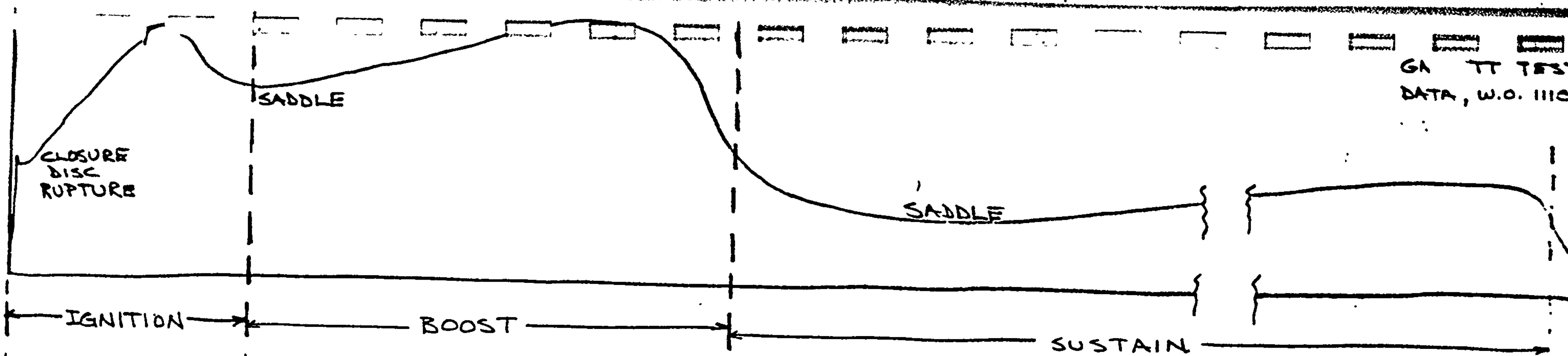
* Pressure Trans. - GAM 1/16" line to trans ~1' Lg vs REI 1/4" line 1"

* G.G. Sealed at REI - opened at GAM for test instrument port

* New parts used for GAM test - Closure trap, disc, etc & Initiator plugs

* Thermocouples - Diff. type & mounted in 1/4" transfer line vs. REI Nozzle cham
  open bead type vs REI's shielded - grounded type

GA TT TEST DATA, W.O. 1110



IGNITION	BOOST	SUSTAIN	
Low rupture press. 570psig Normal Ignition .4 sec 1480 psig Normal temp - 716°F	Normal saddle - 1250psig @ .75 sec Normal Boost - 4.1 sec & 1330 psig High temp 1097°F ∴ High GHP	Normal saddle - 550psig @ 9.2 sec. Gradual increase in press. to 825 psig in 54.5 sec Sustain press. high at 22 sec, over 620 psig Normal Temp 1104°F - GHP in limits	RUN 1 G.G. ONLY AMB.
J_1		H I — UNPREDICTABLE BEHAVIOR	
Low rupture press 650psig High Ignition 1685 psi .3 sec Normal temp - 665°F	Normal saddle - 1275 psig @ .7 sec High Boost press - 1500 psig - 4.4 sec High temp 1076°F ∴ High GHP Erratic temp trace	High saddle press. - 615 psig @ 10.5 sec High sustain press - 850 psig @ 39 sec Press. and temp. step down @ 33 sec 100psig & 150°F Press. high 625 in 52.5 sec, temp 1059°F, GHP in limits	RUN 2 G.G./T.A. AMB
J_1 J_2	J_3	H I — UNPREDICTABLE BEHAVIOR	
Normal rupture - 900 psig High Ignition - 1740 psig, .3 sec Normal temp. - 633°F	High saddle press. 1305 psig @ .8 sec Dip in Boost press @ 1.8 sec, ~100 psi High Boost press 1730 psig - 5.1 sec High temp 1106°F ∴ High GHP	High saddle press - 640 psig @ 8.8 sec High sustain press. - 750psig in 25.4 sec Press & temp. step down @ 25.4 sec, 100 psig & 50°F Press high 725 psig in 49 sec, temp 1072°F, GHP ok	RUN 3 G.G./T.A. 125°F
J_2 F	H I J_3 F	H I — UNPREDICTABLE BEHAVIOR	
Low rupture - 450 psig Low ignition - 750 psig .5 sec Low temp - 348°F	Low saddle press. - 440 psig @ 1.7 sec Low Boost press - 930 psig - 10 sec Long Boost time Low temp. - 580°F ∴ Low GHP	Normal saddle press. - 400 psig @ 14.5 sec Normal sustain press - 485 psig @ 81 sec. Low sustain temp - 806°F ∴ Low GHP	RUN 4 G.G./T.A. -29°F
J_1 G F	F	F — EXCESSIVE HEAT LOSS	
Normal rupture - 1250 psig Low ignition 880 psig - .5 sec Disc leakage - .3 sec Low temp - 350°F	Low saddle press. - 445 psig @ 2.3 sec Low Boost press. - 875 psig - 10 sec Long Boost time Low temp - 482°F ∴ Low GHP	Normal saddle press. - 420 psig @ 17 sec Normal sustain press. - 500 psig @ 77 sec Low sustain temp - 722°F ∴ Low GHP	RUN 5 G.G./T.A.

LIST OF COLD TEST ANOMALY - POSSIBLE CAUSES

A. Grain Anomaly

B. Test Data Error

C. Gas Leakage from Gas Seals

D. Gas Leakage and/or Moisture Leakage past Closure Disc

E. Gas Leakage from instrumentation ports or equipment

F. Different cold conditioning methods (ice build-up)

G. Low Ignitor Output

H. Nozzle Blockage - reduced throat dia.

I. Flow Restriction by clogging either at Thermocouple or stepped line dia. to nozzle.

J1 Generator Design of POM : Closure Disc

J2 Ignitor

J3 Boost Grain

J4 Sustain Grain

K Process or Assembly Error

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Grain Anomaly-e.g., void, crack, bad inhibitor, etc of solid propellant	Increases surface area for burn → rapid changes in gas pressure from normal level to much higher levels	None	• no rapid pressure changes in test data. • consistancy of two identical runs	None

CORRECTIVE ACTION: NONE X REQ'D. (CHECK ONE)

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Data error	Test data instruments fail to measure accurately	None	• correlation of high temp. & amb. data with REI test data • consistancy of two low temp. tests • thermocouple re-calibration • long times gives same area under pressure curves	None

CORRECTIVE ACTION: NONE X REQ'D. (CHECK ONE)

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L DATA-TESTS REQ'D.
Process or assembly error	Unusual behavior due to missing or incorrect material, integral components not assembled, etc,	None	Visual examination of all units during disassembly.	None

CORRECTIVE ACTION: NONE REQ'D. X (CHECK ONE)

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Gas leakage from generator / valve assy gas seals	Increases effective nozzle size → reduces gas pressure from normal level	Low pressure data during ignition and boost	• No leakage observed from any gas seal during visual examinations after test • No leak path discovered during hardware disassembly • Normal pressures during sustain	None

CORRECTIVE ACTION: NONE X REQ'D. (CHECK ONE)

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L DATA-TESTS REQ'D.
Gas leakage and/or moisture leakage past closure disc, environment seal.	Internal gas path leakage will delay closure rupture, also allow moisture to enter chamber - possible water absorption by hygroscopic talley propellants - prior to firing which will affect ignition & propellant burn characteristics by causing local oxygen rich areas resulting in erratic press. spikes.	Test data shows chamber pressure before closure rupture ∴ gas did leak past disc	• Delay in closure rupture did not affect ignition peak pressure characteristic • Pressure data shows smooth transitions and consistant levels with no erratic spikes • Talley advised that 2 hours at 100% humidity will not have measurable effect	Test grains exposed to 100% humidity for one day to determine effect

CORRECTIVE ACTION: NONE

(CHECK ONE)

REQ'D. X

closure disc redesign

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Possible

SPECULATION			EVALUATION	
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L DATA-TESTS REQ'D.
Gas leakage from instrumentation ports or equipment.	Increase effective nozzle size which reduces gas press. from normal level	Low pressure during ignition and boost	• Normal pressure during sustain • High ignition and boost pressures at hot and ambient	None Check instruments for leakage before each firing.

CORRECTIVE ACTION: NONE

(CHECK ONE)

REQ'D. Check instrumentation for leakage before each test

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION			EVALUATION	
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Gas generator design of closure disc or environment seal for chamber pressurization before rupture.	Prevent proper ignition	None	Wide variation in rupture pressure did not affect ignition, boost or sustain during cold, hot or ambient tests	None

CORRECTIVE ACTION: NONE (CHECK ONE)

REQ'D.

Redesign closure disc to

CONCLUSION: Not Cause

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Gas generator design of ignitor	Ignition failure or miss fire	None	Wide variation in ignition performance did not effect generator performance.	None

CORRECTIVE ACTION: NONE (CHECK ONE)

REQ'D. Process control of particle size to eliminate variation of output

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Gas Generator design of boost grain.	Abnormal boost pressure or times	High boost pressures in hot and ambient test - low boost pressure and long times at cold temp.	• High gas pressures at hot and amb. temp. during REI tests • BTU/sec curves for cold tests at Garrett show extreme heat losses during boost	Cold tests to determine heat loss with REI and GAN condition methods Establish real life cold test req't and test method

CORRECTIVE ACTION: NONE

(CHECK ONE)

REQ'D. Redesign boost to reduce gas pressure ∴ GHP and improve transition [illegible]

CONCLUSION: Not Cause

ROOT CAUSE / 1ALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION			EVALUATION	
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Gas Generator design of sustain grain	Abnormal sustain pressure; or time	None	Sustain pressures were normal during cold tests.	None

CORRECTIVE ACTION: NONE X REQ'D. (CHECK ONE)

CONCLUSION: Not Cause

W.O. 1110

ROOT CAUSE ALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Unlikely

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Nozzle blockage or flow restriction	Clogging of transfer line by thermocouple or stepped inlet to GAM nozzle or reduction of nozzle throat diameter by deposited gas particles - This will be observed by pressure increases above normal or predicted levels.	None - during cold tests ... But erratic and unpredictable pressure during hot and amb.	Normal pressures during cold tests in sustain phase	Repeat ambient tests with improved filters

CORRECTIVE ACTION: NONE

(CHECK ONE)

REQ'D.

Improve gas filters, if necessary.

CONCLUSION:

Not Cause

ROOT CAUSE ALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Possible

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Low ignitor output	• Insufficient ignitor output to produce pressure and temp. req'd to ignite propellant grains • Excessive heat loss slows burn rate	Low pressure and temperature traces during cold tests	• Propellant grains ignited although boost outputs were low. • Excessive heat losses during ignition and boost saddle are shown in BTU/sec curves of plotted test data This would suppress propellant output	Ignitor only tests or ignitor and boost grains under cold/dry conditions and cold/humid conditions.

CORRECTIVE ACTION: NONE X REQ'D. (CHECK ONE)

CONCLUSION: Not probable cause

ROOT CAUSE ANALYSIS CHART

FAILURE INDICATION: Garrett Cold Temp. Test Anomaly

CAUSE PROBABILITY ESTIMATE: Probable

SPECULATION		EVALUATION		
FAILURE MODE	FAILURE SEQUENCE	SUPPORTING DATA	REFUTING DATA	ADD'L. DATA-TESTS REQ'D.
Different conditioning methods (ice-build-up)	• REI and GAM cold conditioning methods produce different system heat losses • Excessive heat loss suppresses propellant output	• Low propellant ignition boost & sustain output during cold GAM tests • Normal propellant output during REI cold tests • Ice observed during GAM conditioning and large puddle of water after test • Skin temperature of gas generator approx 20°F greater during REI testing • Grain temp. identical.	None	Repeat GAM tests using transfer tube, thermocouple ports, and nozzle with • REI conditioning cold test • CO_2 with ice build-up cold test • Cold test in conditioning chamber with no ice.

CORRECTIVE ACTION: NONE

REQ'D. (CHECK ONE) Further testing

CONCLUSION: Root Cause

TEST PLAN : ANALYZE GAS GENERATOR

COLD TEMP. TEST ANOMALY

3 Units : REI gas gen. & valve / GAM transfer tube & nozzle

Test 1 : REI condition method -25°F

Test 2 : GAM condition method -25°F

(CO_2 with ice-build-up)

Test 3 : -25°F conditioned in temperature chamber with no ice (min. ice)

Evaluate test data : establish further cold testing

2 Units : REI gas gen. with improved filter

Test 1 : ambient - GAM transfer tube & nozzle

Test 2 : ambient - REI 5" transfer tube & nozzle